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Technology Evaluation
Operable Unit No. 20 (Site 86)
Marine Corps Base
Camp Lejeune, North Carolina

Prepared for

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EXECUTIVE SUMMARY

A technical evaluation (TE) of potential remedial technologies was prepared to facilitate the selection for treatability (pilot) testing at Site 86. This TE was not intended to be an exhaustive review of all remediation technologies, but rather a focused review of technologies that have been demonstrated to be effective for "hot spot" treatment. The evaluation included innovative strategies for *in-situ* groundwater remediation that may not have been used at Camp Lejeune, but are considered promising or "emerging" technologies.

Two contaminant plumes have been identified in the vicinity of Site 86: a smaller plume, located immediately southwest (upgradient) of the site, near the former wash rack area; and a much larger, more concentrated plume, that extends 1,700 feet downgradient of the site. The extent of the smaller plume has not been defined, and efforts to delineate this plume are ongoing. The larger plume appears to originate near the southeast corner of the site and is most concentrated at depths ranging from 40 to 50 feet below grade. In both plumes, TCE is the principal contaminant, and cis-DCE is a lesser contaminant. TCE appears as the most-extensively distributed compound and is generally found in highest concentrations in the Castle Hayne aquifer.

The objective of the pilot test will be to test the effectiveness of a treatment technology to reduce TCE concentrations within the larger, downgradient plume at Site 86 in the "hot spot" areas. The target "hot spot" area for pilot testing was selected based on a concentration of 200 µg/L TCE in groundwater. TCE is most highly concentrated in two areas: 1) immediately adjacent to the southeast corner of the site, at depth intervals of 30-34 and 50-54 feet bgs; and, 2) approximately 700 feet downgradient of the site, at a depth interval of 40-44 feet bgs. CH2M Hill recommends that the area located 700 feet downgradient of the site be the focus of the pilot test. The target area is approximately 400-500 feet long and approximately 100 feet wide. Because of the depth and elongated nature of the plume, a horizontal well is considered the most effective method to address the target area.

Four technologies, suitable for use with a horizontal well, were evaluated. These four are:

1) air sparging/biosparging,
2) hydrogen sparging,
3) co-metabolic (methane or propane) sparging,
4) ozone sparging.

The first technology, air sparging/biosparging, was eliminated from consideration, because of the fact that soil vapor extraction would be required to capture sparged air, and unamended aerobic biodegradation of TCE is infeasible.

The remaining three technologies were evaluated for effectiveness and implementability. Test costs were evaluated for implementation and one year of operation.

Based on comparison of the technologies, ozone sparging is considered to have the greatest potential for success and is recommended as the preferred technology for implementation at Site 86.

Predictive groundwater modeling using BIOCHLOR was performed to evaluate the potential for continued off-site migration of the contaminant plume. Based on results of the BIOCHLOR modeling, "hot spot" remediation activity at Site 86 will reduce the distance of plume migration by approximately 1,200 feet and reduce the time to achieve steady state conditions by approximately nine years.

The recommended approach for implementation of ozone sparging at Site 86 is to use an approximately 400 foot long directionally drilled horizontal well. The horizontal well would be designed to deliver ozone to the target area of the plume. After the one year period (or less) of pilot test operation, a decision will be made to continue operation, discontinue the test, or evaluate a different technology, such as hydrogen or co-metabolic sparging. Based on the results of pilot test, horizontal well sparging technology may be applied to other areas of the Site 86 plume or at other Sites at Camp Lejeune.

1.0 Introduction

1.1 Purpose of the Technology Evaluation

This document provides a technical evaluation (TE) of potential remedial technologies to facilitate the selection of an effective approach for treatability (pilot) testing at Site 86. This document is not intended to be an exhaustive review of all remediation technologies, but rather a focused review of technologies that have been demonstrated to be effective for "hot spot" removal, with subsequent natural attenuation of the stabilized plume. The evaluation focused on innovative strategies for *in-situ* groundwater remediation that may not have been used at Camp Lejeune, but are considered promising or "emerging" methodologies.

Following review of this report by the Camp Lejeune Partnering Team, the selected remedial technology will be tested in a pilot study at Site 86. The methodology of the pilot study will be documented in the Treatability Study Work Plan. The technology(s) used for full-scale remediation of Site 86 will be addressed in a future feasibility study.

1.2 Report Organization

The purpose of this TE document is to develop and evaluate a range of remedial action alternatives that could be implemented for groundwater beneath Site 86.

This report contains seven sections and appendices, which address groundwater contamination at Site 86. The report is organized as follows:

1.0 **Introduction** – Presents the purpose of the Technology Evaluation for this site.

2.0 **Site Information** – Provides an overview of the site history, geology, hydrogeology, and contamination.

3.0 **Pilot Test Objective and Definition of "Hot Spot" Area** – Defines pilot test objectives and identifies the hot spot targeted for this evaluation.

4.0 **Technology Identification and Screening** – Presents the factors used in selecting a remedial technology, classes of technologies, the selected technologies, and a cost analysis.

5.0 **Comparison of Technologies** – Relative comparison of the technology options

6.0 **Predictive Modeling for Natural Attenuation** – Details the objectives, approach, and results from BIOCHLOR modeling.

7.0 **Recommendations** – Discusses the conclusions and recommendations resulting from the evaluation of the selected technologies against the objectives of the TE.

8.0 **References** – Lists the references used in this document.

2.0 Site Information

2.1 Facility and Site Description

Background information for Site 86 is contained in the *Amended Remedial Investigation, Operable Unit 20, Site 86, Tank Area AS419 - AS421* (Baker Environmental, May 2002). A detailed discussion of the Site background and previous investigations is contained in the Baker report; a brief summary is provided in the following sections.

2.1.1 Facility and Site Physical Setting

MCB Camp Lejeune is located in Onslow County, North Carolina and covers approximately 236 square miles and includes 14 miles of coastline. The Base is bounded to the southeast by the Atlantic Ocean and to the northeast by State Route 24. The town of Jacksonville, North Carolina is located north of the Base.

Site 86 is part of Operable Unit (OU) Number (No.) 20, located within the Marine Corps Air Station (MCAS), New River section of Camp Lejeune (Figure 2-1). The site is located on the southwest corner of the Foster and Campbell Street intersection, within the operations area of MCAS New River. The site is comprised of a grassy field surrounded by several buildings, asphalt roads, and parking lots.

The ground surface at Site 86 gently slopes to the south, toward a drainage ditch and culvert. Storm water drains located along Campbell Street receive runoff from only the northernmost portion of the study area. Storm water from Site 86 eventually discharges into the New River approximately three-quarters of a mile to the east. Some important adjacent areas include Buildings AS504 and AS510. According to the Navy Historian (Baker, 2002), drawings of the original hangar (Building AS504) indicate that there were numerous shops in the building that included a carburetor shop, a battery shop, a paint shop, and an engine build-up shop. Building AS510 was constructed in 1994 as a training facility. Prior to 1994 the site was used as a hardstand parking area for tank trucks, a power plant (AS422) that provided steam heat to surrounding buildings, a parachute loft, a Battery Shop, and a parking lot for military and civilian automobiles. Also, a sanitary sewer from Building AS504 ran beneath where Building 510 is currently located.

2.1.2 Site History

OU No. 20 (Site 86) served as a storage area for petroleum products from 1954 to 1988. The MCAS New River station was originally an outlying field used in support of the Cherry Point Marine Corps Air Station. It was dis-established after World War II and re-commissioned in 1951. Early records suggest that Site 86 was not developed until 1954. In 1954, three 25,000-gallon above ground storage tanks (ASTs) were installed within an earthen berm. The three tanks were reportedly used for No.6 fuel oil storage until 1974. From 1979 to 1988 the tanks were then used for temporary storage of waste oil. The three tanks were emptied in 1988, and cleaned and removed in 1992. Today, Site 86 is grass-covered and only a very slight depression remains where the tanks were removed.

Over the course of several investigations since 1992, the plume at Site 86 has migrated away from the source area and now extends several hundred feet off-site. Therefore, for the purposes of this TE, "Site 86" or "site" will be used in a general sense to refer to the entire contaminated area in and around the property boundary.

2.2 Summary of Remedial Investigation

Baker Environmental (Baker) initiated a remedial investigation at Site 86 in the spring of 1995. The investigation focused on the former AST tank farm, located in the west central portion of the original Site (Figure 2-2). Based on the results of the RI, as well as previous investigations by other consultants prior to 1995, it was determined that no significant impacts to surface and subsurface soil, as well as the surficial aquifer had occurred. However, contamination in the upper portion of the Castle Hayne aquifer was evident. The highest levels of groundwater contamination were observed in the upper portion of the Castle Hayne aquifer. Post-RI field work in 1997 and 1998 included the installation of new monitoring wells and collection of groundwater samples. This work identified a large plume extending east-northeast from Site 86, as well as a much smaller plume to the southwest, near a former wash rack area. Results of 1997-1998 work were documented in the *Amended Remedial Investigation, Operable Unit 20, Site 86, Tank Area AS419 - AS421* (Baker, May 2002). Based on contaminant concentration trends from long-term quarterly and annual monitoring performed by Baker through 2002, plume stabilization has not been observed. Groundwater contamination has not impacted any receptors (i.e., potable water supply wells and surface water bodies). Based on the data reviewed to date, stormwater ponds located downgradient of the site may be sampled for COC's in the future at the request of EPA as further verification to support the current conclusion that receptors are not impacted at this site.

2.2.1 Geology and Hydrology

The RI report (Baker, 1998) provides details regarding local geology and the occurrence of surface water and groundwater resources at Site 86. The following is a brief summary of these features.

2.2.1.1 Geology

Figures 2-3 and 2-4 illustrate the stratigraphy at Site 86.

The regional geology is described in the "Hydrogeologic Framework of U.S. Marine Corps Base at Camp Lejeune, North Carolina" (Cardinell, et al., 1993). The generalized North Carolina coastal plain sequence is (youngest to oldest) Undifferentiated, Yorktown, Eastover, Pungo River, Belgrade Formation, and Castle Hayne Group. The Yorktown, Eastover, and Pungo River Formations, however, have not been identified at Camp Lejeune. The Castle Hayne Group contains the Castle Hayne aquifer, a major regional source of water supply.

A fairly consistent depositional sequence was observed in the borings throughout Site 86. During the RI, the Undifferentiated and River Bend Formations were encountered. The Belgrade Formation is absent locally. The Undifferentiated Formation is comprised of loose to medium dense sand and soft to medium stiff clay. This formation is comprised of several units of Holocene and Pleistocene age and may consist locally of a fine to coarse sand, with lesser amounts of silt and clay. At Site 86, this formation typically extends to a depth between 20 and 30 feet below ground surface (bgs). Beneath the Undifferentiated Formation lies unconformably the River Bend Formation (upper part of the Castle Hayne aquifer). This unit, which is predominantly composed of dense to very dense shell and fossil fragments interbedded with calcareous sands, occurs at approximately 30 to 200 feet bgs.

2.2.1.2 Hydrogeology

The surficial aquifer resides within the Undifferentiated Formation, and the Castle Hayne aquifer resides locally within the River Bend Formation. Depth to groundwater typically ranges from five to nine feet bgs and varies seasonally. The Belgrade Formation, which typically acts as a confining unit between the surficial and the Castle Hayne aquifers at Camp Lejeune, was not encountered at Site 86.

Based on permeability ("slug") tests and pumping experiments performed by Baker, the average hydraulic conductivity of the surficial aquifer is 9.7×10^{-4} cm/s. The average hydraulic conductivity of the Castle Hayne aquifer is 1.2×10^{-3} cm/s. The average yield from a two-inch diameter monitoring well in the surficial aquifer is ½ to 3 gallons per minute (gpm).

Monitoring wells at Site 86 are distinguished as "shallow", "intermediate", and "deep" relative to their position within the surficial aquifer and Castle Hayne. Shallow wells are screened within the surficial aquifer, at total depths of less than 30 feet. Intermediate wells are screened from approximately 30 to 65 feet. Deep monitoring wells are screened from approximately 80 to 95 feet.

Groundwater flow direction in the surficial aquifer appears to be divergent. During the RI (Baker, 1998), groundwater flow was to the north across Site 86, toward Stick Creek, along a gradient of approximately 0.005 feet/foot. During Post-RI Monitoring, the general direction of groundwater flow was toward the north; however, there are seasonal components to the east and south-southeast. The hydraulic gradient ranges from 0.002 feet/foot to 0.008 feet/foot.

Groundwater flow in the upper portion of the Castle Hayne aquifer is fairly consistent. During the RI, flow was to the northeast, toward New River, on a gradient of approximately 0.003 feet/foot. During Post-RI Monitoring, groundwater flow has been to the northeast or east- northeast, on a gradient of between 0.003 feet/foot and 0.005 feet/foot.

Groundwater flow direction indicated by the "deep" monitoring wells in the Castle Hayne aquifer is also relatively consistent. During the RI, flow was to the east-northeast across the site, on a gradient of 0.003 feet/foot to 0.005 feet/foot. During Post-RI Monitoring, groundwater flow has been to the north-northeast or east- northeast, with the exception of July 1998, where flow was to the east. The gradient ranged from a low of 0.002 feet/foot in July 1998 to 0.006 feet/foot in October 1999.

According to Baker (RI report, 1998), there is a direct hydraulic connection between the surficial aquifer and the Castle Hayne at Site 86. The evidence includes common water level fluctuations between shallow, intermediate, and deep wells, and no evidence of the Belgrade Formation (confining layer) in site borings.

2.2.2 Groundwater Use

MCB Camp Lejeune water is supplied entirely from groundwater. In the late 1980's, groundwater usage was estimated at over seven million gallons per day (Harned, et al., 1989). Groundwater is pumped from approximately 84 supply wells and treated at five water treatment plants with a total capacity of 15.8 mgd; however, the plants are currently producing 6.5 mgd.

All supply wells pump from the Castle Hayne Aquifer. The Castle Hayne Aquifer is a highly permeable, semiconfined aquifer that is capable of yielding up to 1,000 gallons per minute (gpm) to wells in the MCB Camp Lejeune area. The water is typically hard, calcium bicarbonate type.

One water supply well, designated PSWAS-131, was identified within a 1,500 foot radius of Site 86 during the RI (Baker, 1998). The well is approximately 1,200 feet west-northwest of the site, hydraulically upgradient or cross-gradient from the site. Baker (1998) reported PSWAS-131, which is approximately 200 feet in depth, to be inactive.

2.2.3 Nature and Extent of Contamination

According to the RI (Baker, 1998), two contaminant plumes have been identified in the vicinity of Site 86: a smaller plume, located immediately southwest (upgradient) of the site, near the former wash rack area; and a much larger, more concentrated plume, that extends 1,700 feet downgradient of the site. The extent of the smaller plume has not been defined, and efforts to delineate this plume are ongoing. The larger plume appears to originate near the southeast corner of the site and is most concentrated at depths ranging from 40 and 50 feet bgs. Figures 2-5 through 2-10, reproduced from Baker (2002), show the horizontal distribution of perchloroethene (PCE), trichloroethene (TCE), and cis-1,2 dichloroethene (cis-1,2 DCE) (a degradation product of PCE/TCE), at depths of 30-34 feet, 40-44 feet, 50-54 feet bgs. These plume maps are based on a compendium of August 2001 and January 2002 groundwater analytical data. Figures 2-11 through 2-13 present cross sectional views of the plumes for each of the same compounds. Note that plume maps were not generated for vinyl chloride, because detections of vinyl chloride have been sporadic and vinyl chloride occurs at very low concentrations. Also note that the North Carolina "2L" clean-up standard (0.015 μg/L) for vinyl chloride is less than the typical laboratory detection limit of 1 μg/L.

In both plumes, TCE is the principal contaminant, and cis-DCE is a lesser contaminant. TCE appears as the most-extensively distributed compound and is generally found in highest concentrations in the Castle Hayne aquifer, at a depth between 40 and 50 feet bgs. Concentrations of TCE and cis-DCE are generally less than 400 μg/L. The highest concentration of any compound detected was TCE at 3,758 μg/L, from a groundwater sample collected using Geoprobe from a depth of 30 to 34 feet bgs. This result is questionable because at the 20 to 24 foot sample was non-detect and 40 to 44 foot sample contained a TCE concentration of only 41 μg/L.

There is no evidence to suggest that a continuing source (i.e., leaching from the vadose zone) is present at, or in the vicinity of, Site 86. Contaminant concentrations in groundwater less than 30 feet deep are low. Additionally, the subsurface soil sampling from the RI indicated only low levels of VOCs (i.e., generally less than 5 μg/kg) in the vicinity of the former ASTs. For these reasons, soil (vadose zone) remediation is not considered to be necessary at Site 86, and will not be discussed in this document.

The appearance of "hot spots" along the plume length could be attributable to either "plug" contaminant flow or multiple sources. "Plug flow" could be caused by one or more high-volume, brief releases from the source (Site 86), rather than a low-volume, constant leak. Such "plugs" are manifest by "hot spots" near the leading edge of a plume, with relatively dilute concentrations in trailing areas

Although a formal natural attenuation study for Site 86 has not been conducted, the process of natural attenuation at Site 86 appears stagnated, i.e. appears to resemble "Type III" behavior, per EPA technical protocol (EPA, September, 1998). As indicated in Figures 2-5 through 2-10, the TCE plumes are much larger and more concentrated than the cis-1,2 DCE plumes. Stagnation is likely caused by a lack of naturally occurring carbon (fermentation substrates) in the aquifer.

2.2.4 Baseline Risk Assessment

A Baseline Risk Assessment (BRA) was conducted at Site 86 to evaluate potential risk to human health. Current exposure scenarios that were evaluated included adolescents and adults who either reside at the base (current military personnel), or are visitors. Future exposure scenarios that were evaluated included the adult and child residents and construction workers.

The baseline risk assessment indicated potentially unacceptable carcinogenic risk for the future adult and child residents from exposure to vinyl chloride and TCE in the groundwater. The BRA also indicated potentially unacceptable noncarcinogenic hazard levels for the future adult and child residents, primarily from exposure to iron and arsenic in the groundwater. The compounds of concern (COCs) that will be addressed by technologies discussed in this TE are vinyl chloride and TCE.

3.0 Pilot Test Objective and Definition of "Hot Spot" Area

3.1 Pilot Test Objective

The objective of the pilot test is to test a technology's ability to treat a "hot spot" and reduce TCE concentrations within the Site 86 plume to low levels, where natural attenuation could complete the process of meeting regulatory standards. Additional goals include:

- Contaminant reduction in groundwater of greater than 80 percent
- Minimizing the size and migration of the plume

3.2 Defining "Hot Spots"

Based on engineering judgment, a "hot spot" is generally considered to be an area containing COC concentrations significantly higher than the regulatory standard, usually at least two orders of magnitude or more. The North Carolina groundwater standard for PCE is 0.7 μg/L, TCE 2.8 μg/L and cis-1,2-DCE 70 μg/L.

The target area for pilot testing was selected based on a concentration of 200 μg/L TCE in groundwater, which, for the purpose of this TE, defines the "hot spot". TCE is most highly concentrated (Figures 2-6, 30-34 feet; 2-7, 40-44 feet; and 2-9, 50-54 feet) in two areas:

1) the "wash rack" area, positioned immediately adjacent to the southeast corner of the site, at depth intervals of 30-34 and 50-54 feet bgs; and,
2) the area positioned approximately 700 feet downgradient of the site, at a depth interval of 40-44 feet bgs.

CH2M Hill recommends that the area located approximately 700 feet downgradient of the site be the focus of the pilot test, because of the uncertainty associated with the elevated concentration of the sample located at the southeast corner of the original site. The target area, indicated in Figure 3-1, is approximately 400-500 feet long and approximately 100 feet wide. Pilot testing and/or treatment of the upgradient ("wash rack") area is not recommended until the extent of the plume at that location has been defined. Information from the pilot study may be used to address the upgradient plume in the future.

4.0 Technology Identification and Screening

4.1 Factors in Selecting a Remedial Technology

This section describes the applicable remedial technologies and evaluates their potential for addressing "hot spot" contamination at Site 86. Included is a discussion of the general and site-specific factors that must be considered when evaluating remedial options. These factors include:

- Environmental media to be remediated;
- Remediation objective;
- Contaminant characteristics and concentrations;
- Site hydrogeology;
- Site constraints;

4.1.1 Environmental Media

As stated in Section 2.2.3, there is no evidence to indicate the presence of a continuing vadose source at Site 86. Therefore, the environmental media of concern for the subject TE is only groundwater. The target depth is 40 to 44 feet bgs. This is the predominant depth with the greatest extent of TCE contamination.

4.1.2 Remediation Objective

As stated in Section 3, the purpose of the pilot test at Site 86 is to test a technology at "hot spot" areas of the groundwater plume with TCE concentrations greater than 200 μg/L. The objective of the pilot test will be to reduce concentrations in this area by at least 80%, and minimize the plume size and migration.

40 ug/L 50ug/l

4.1.3 Contaminant Characteristics and Concentrations

Contaminant characteristics and concentrations affect the technology screening process. The primary contaminant at Site 86 is TCE, a chlorinated aliphatic compound, which is a slightly soluble, highly volatile compound. The NC groundwater standard for TCE is 2.8 μg/L. TCE is biodegradable under anaerobic, strongly reducing conditions. The concentrations of TCE within the target "hot spot" area ranges from 200 to 500 μg/L.

4.1.4 Site Hydrogeology

Site hydrogeology is another key component of the technology screening process. Low permeability and/or heterogeneous conditions are generally problematic in terms of cost-effective remediation. Baker has described the target area of the upper Castle Hayne aquifer as fine grained sand and silt. As stated in Section 2.2.1.2, the hydraulic conductivity is in the low 10^{-3} cm/s range. Based on inspection of drilling logs and cross-sectional diagrams, the material at 30-50 feet below grade in the target area appears to be generally well sorted (i.e.

fairly uniform). These conditions are favorable for in-situ air based injection treatments, such as air sparging, and adequate for some pump and treat options.

4.1.5 Site Constraints

Site constraints are surface or subsurface physical conditions that represent challenges or actual impediments to remediation construction activity. Such conditions include unusually great depths of contamination and unusually large plumes. The presence of buildings, roadways and/or high traffic areas, buried and overhead utilities, infrastructure, surface water bodies, concrete or asphalt paving, etc can impede plume access via drilling. Most of these access constraints can be overcome with coordination with Base activities.

The downgradient "hot spot" area at Site 86 underlies occupied buildings and open field.

4.2 Classes of Technologies

In accordance with the criteria discussed in Section 4.1, three general classes of in-situ groundwater remediation technologies were selected for further evaluation. These three general categories of remedial options are:

- Mass Transfer (Stripping)
- Enhanced Biodegradation
- Oxidation (chemical treatment)

Note that thermal treatment technologies are generally impractical for plumes lacking free phase product. For this reason, thermal treatment was not considered for Site 86.

The evaluation was based on the following criteria:

- Effectiveness, which relates to remediation objective and contaminant characteristics and concentrations (sections 4.1.2 and 4.1.3), and;
- Implementability, which relates to site hydrogeology and site constraints (sections 4.1.4 and 4.1.5).

Each general category of technology includes two primary components:

1) the method of chemical/substrate delivery to the subsurface; and,
2) the actual chemical, substrate, or fluid that will effect remediation.

Both components are described in the following sections. The first component is generally the most complex and difficult engineering problem at remediation sites.

4.2.1 Chemical/Substrate Delivery Options

Chemical or substrate delivery can be accomplished using either vertical borings/wells or horizontal borings/wells; both have proven effective in the field. The following sections compare and contrast both horizontal and vertical wells/borings in terms of effectiveness, implementability, and cost.

Effectiveness

Vertical wells are most effective for small scale, shallow plumes. Horizontal wells are most effective for large, deep plumes. The effectiveness of a horizontal well is more sensitive to careful design, since non-uniform flow over a long screen may occur. A horizontal well is also more susceptible to "short circuiting" caused by subsurface heterogeneity. Fortunately, the target impacted vertical zone (40 to 50 feet bgs) at Site 86 appears to be relatively homogeneous, and is therefore suitable for a horizontal well.

Implementability

The elongated shape, depth, and presence of the Site 86 plume beneath various surface structures strongly favor a horizontal well approach.

A single horizontal gas sparge well submerged at least 20 to 25 feet below the water table interface will typically have a minimum "influence zone" approximately 100 feet wide near the interface. Such a well could be used for delivery of gaseous substrates/oxidants via sparging. The large influence zone is due in part to the fact that soil overlying the well is not disturbed during the drilling process, and preferential flow pathways are not created. The total area treated by a 400-ft long horizontal sparge well installed 20 ft below the water table would be approximately 48,000 square feet. Approximately 70 vertical wells, each with a 15 foot "radius of influence", would be required to treat the same area. In addition, the open area of the well screen exposed to the "core" area of the contaminant plume is small using vertical wells. Most vertical sparge/injection wells use 1 to 2 ft long screens, and the radial distribution of air from these short screens is only a few feet at the depth of injection. By contrast, horizontal wells allow a large open area of screen to be positioned in a discrete vertical interval, with relatively high contact efficiency within that interval.

Other factors favoring horizontal well use at Site 86 include the following:

- The time frame associated with installing 70 vertical wells at Site 86 is estimated to be six weeks using two drilling rigs. The estimated time frame to drill one 400-ft horizontal well is 15 days or less.
- Vertical wells will require installation of a complex system of horizontal conveyance manifolds, piping, and valves, and appurtenances. "Flow balancing" between groups of vertical wells is time consuming, and must be performed periodically (O&M).
- A significant portion of the Site 86 plume, both the overall plume and the target area for the pilot test, underlies buildings and/or high traffic areas, which would make installation of vertical wells and above ground piping difficult or impossible. Directional drilled horizontal wells result in minimal disruption to the site.

Direct injection of liquid chemicals or substrates through individual borings was also considered. Because the dispersion of liquid chemicals or substrates in the subsurface tends to be less uniform or efficient than that of a gas, borings would need to be spaced closer to each other than for air sparging. Gas flow from horizontal wells would have to be monitored to ensure proper flow and pressure along the entire length of well for uniform fluid distribution.

Vendors such as Regenesis (ORC™/HRC™), BMS (Biox™), and others recommend well spacing of 12 feet (six-foot "radius of influence"). Based on this spacing, the number of borings required to address the target area is 48,000/113 = 425 borings. Even if direct push methods could be used (which is questionable for depth of the target treatment zone), the number of vertical borings to start the pilot test would be cost prohibitive. At full scale, a second or third "polishing" episode of injection may also be required, which could double or triple the cost of delivering the substrate.

Cost

The estimated cost of drilling and installing a vertical well to 50 feet is approximately $4,200, including mobilization, materials, development, and disposal of soil cuttings and development water. The total cost of vertical wells for the pilot test varies greatly, depending on spacing and the area of coverage desired, relative to the target area, Figure 3-1. Assuming a maximum effective sparge radius of 15 ft, approximately 70 wells would be required to address the entire target area. Therefore, the approximate cost of vertical sparge wells would be $295,000. The target area could also be addressed using a single 400-ft long horizontal well. The estimated cost for a horizontal well, including 500 feet of entry/exit length (900 feet total) is approximately $180/ft, or $162,000; including mobilization, materials, development, and disposal of soil cuttings and development water.

Alternatively, a small section of the target area could be addressed during the pilot test using only a few vertical wells, to save costs. Such an approach would provide useful data; however, it would be difficult to compare vertical well performance data from a pilot test in a small area to a horizontal well, in terms of possible full scale implementation. Furthermore, remediation of a small section of the downgradient plume during the pilot test will do little to mitigate plume expansion. Continued plume expansion during the pilot test period will likely result in increased full-scale remediation costs.

In summary, a horizontal well is recommended for Site 86. If horizontal well remediation proves successful for the portion of the plume located 700 feet downgradient (target area); a second horizontal well could be installed at the upgradient area of the Site.

4.2.2 Chemical/Substrate Options

Chemicals and substrates (as well as carrier fluids) used to promote *in-situ* volatilization, biodegradation, oxidation, and reduction can be injected in liquid or gaseous form. In the case of a horizontal injection well, achieving uniform distribution of injected fluid is a key engineering challenge. Because liquids are much more dense and viscous than gases, it is generally more difficult to promote uniform flow of liquids within long horizontal screens (i.e. greater than 100 feet). Furthermore, there is little or no motive force to "push" the injected liquid away from the well. Therefore, injected liquids will tend to "pool" around the well, generally in an oval-shaped zone.

In contrast, gas flow achieves a far more uniform distribution of substrate/chemicals both horizontally and vertically, aided by the low density and buoyancy of the gas (provided that the sparge well is positioned adequately below the water table). Gas-phase delivery of chemical or biological substrate within horizontal wells is also preferred for the following reasons:

- Horizontal wells are difficult to rehabilitate if fouling or scaling on the screen should occur. Fouling and scaling are more likely from liquid injection.
- Gas blending, if required, is generally more uniform than liquid blending.
- Equipment for gas blending and injection is typically more reliable, less maintenance intensive and less expensive than equipment for liquid injection.

It should be noted that, even for gas injections, achievement of uniform flow across the entire length of a long horizontal screen can be challenging, necessitating an engineered screen with non-uniform slot size/spacing.

Based on the selection criteria of Section 4.1 and the information contained in Section 4.2, gas injection using a horizontal well is recommended at Site 86. The corresponding selected technologies are as follows:

- Air Sparging/Biosparging (unamended air)
- Hydrogen Sparging
- Co-metabolic Air Sparging
- Ozone Sparging

4.2.2.1 Air Sparging

GENERAL DESCRIPTION

Air sparging involves the injection of air into the aquifer or water-bearing zone at a depth of at least 10 to 30 feet below the water table interface. The injected air rises through the saturated zone in a complex and non-uniform series of finger-like channels, the path of which is strongly influenced by subsurface heterogeneity. Air sparging can be used to induce mass transfer ("stripping") of volatile organic compounds from groundwater and/or aerobic biological degradation.

EFFECTIVENESS

Air sparging of plumes containing chlorinated solvents is well known, with numerous field applications successfully completed, or in process. Contaminant laden vapor is collected using soil vapor extraction (SVE), treated, and discharged to the atmosphere ..

IMPLEMENTABILITY

Conventional air sparging was not considered for this TE because SVE is required for vapor capture. Installation of a directionally drilled SVE well or horizontal "trench well" at Site 86, as well as vapor collection and extraction/treatment equipment, would be difficult and significantly increase costs. The difficulty is due to a high water table and the presence of structures in the treatment area. The vapor recovery well would have to be in the vadose zone, which is not very thick. Preliminary estimates indicate this approach would double the cost of the pilot test.

Air sparging could be conducted without vapor recovery. However, Camp Lejeune has had a problem with off gas from a remediation system in the past, and with no vapor recovery system in place, the possibility of creating another indoor air quality issue would exist.

Therefore, air sparging is eliminated from further consideration based on vapor collection issues.

4.2.2.2 Hydrogen Sparging

GENERAL DESCRIPTION

Hydrogen sparging is a derivative of biosparging, and was recently developed for remediation of chlorinated solvent plumes. Hydrogen is injected into the aquifer or water bearing zone to stimulate anaerobic halorespiration, a form of reductive dechlorination (RD). RD is a biologically mediated reaction in which the chlorinated molecule acts as an electron acceptor, and a chlorine atom is replaced with a hydrogen atom, which acts as the electron donor.

EFFECTIVENESS

Hydrogen gas is typically injected on a low volume, pulsed basis. Continuous injection is not cost effective or necessary. For dechlorination to occur at low hydrogen concentrations, bacteria (termed halorespirators) must compete successfully with other hydrogen-using bacteria for the available hydrogen. Recent studies (Newell, et al 1997) indicate that dechlorination is not affected by competition for electron donors at elevated hydrogen concentrations; therefore, increasing the amount of hydrogen within a plume will result in increased halorespiration. The same studies indicate extensive biological dechlorination (as high as 95% removal of total chlorinated ethenes) can be achieved using hydrogen sparging.

IMPLEMENTABILITY

For most applications, hydrogen gas is stored on-site in large "tube trailers" or bundles of welding gas type vessels, either pre-mixed or blended with nitrogen on-site. Since the gas is under high pressure, a blower or compressor system is not required. The gas is metered directly into the sparge well(s) using an injection manifold, controlled by a programmable timer. System maintenance is minimal. A possible concern associated with hydrogen injection is the potential accumulation of fugitive gas in buildings, and/or production of by-products, such as hydrogen sulfide gas. The target area for the pilot test is mostly covered by grass, so these issues are not considered to be pre-emptive. Furthermore, since the depth of sparging is 40-50 feet bgs, dilution of the small volume of sparged gas in the vadose zone should mitigate the potential for accumulation in buildings. Monitoring devices could be installed in or around structures near the pilot test area during operation that monitor for hydrogen sulfide.

COST

For the purposes of the cost estimate, it has been assumed that hydrogen would be stored on site in bundles of welding gas vessels and injected in five minute bursts on a weekly basis. The total flow rate is estimated to be 200 cfm, or approximately 0.5 cubic feet per minute (cfm) per foot of screen. The cost for a hydrogen sparge pilot test is estimated to be $630,000. Of this cost, $523,000 is required for the installation of the system and $107,000 is required for operation and monitoring. The cost estimate in Appendix A is budgetary; to be used for comparison purposes only. The time frame for the field demonstration was assumed to be one year; therefore, "present worth" costs were not calculated.

4.2.2.3 Co-metabolic Air Sparging

GENERAL DESCRIPTION

Co-metabolic sparging involves injection of air, amended with a nutrient gas, typically propane or methane at less than 5% by volume. Another derivative of biosparging, the objective of co-metabolic sparging is to inject only the amount of air and nutrient required meeting stoichiometric demands for biological halorespiration, rather than promoting volatilization.

It is generally accepted that direct halorespiration (RD) does not occur under aerobic conditions. However, if conditions are favorable, co-metabolism may occur. During co-metabolism, microorganisms gain carbon and energy for growth from metabolism of a primary substrate, and chlorinated solvents are degraded fortuitously (i.e. non-selectively) by enzymes present in the metabolic pathways (Newell, 1999). The organism apparently obtains no benefit from the biodegradation of the chlorinated solvent. Literature review indicates that TCE can be co-metabolized, and "daughter products" such as DCE and vinyl chloride can be degraded aerobically.

EFFECTIVENESS

Although a relatively new approach, co-metabolic sparging has seen impressive results in several field demonstrations for TCE plumes (ESTCP, 2001). Technology vendors such as PHA Environmental Restoration, among others, specialize in co-metabolic and nutrient gas sparging.

IMPLEMENTABILITY

Co-metabolic sparging, using air amended with nutrient gas (or gases) is considered feasible for treatment of chlorinated solvents at Site 86. Because air is injected, aerobic conditions prevail within the plume. Unlike hydrogen sparging, a bench scale (laboratory) study using saturated soil and groundwater from the site would be required to determine if native conditions are favorable for co-metabolic biodegradation of target compounds. The bench testing would also be necessary to select the most effective type of nutrient gas and percentage of nutrient gas in air. In order to reduce gas consumption and improve efficiency, most nutrient gas sparge systems are designed to inject on a periodic or "pulsed" basis.

Similar to hydrogen sparging, the primary concern associated with propane or methane injection is the potential accumulation of fugitive gas in buildings, and/or production of by-products. Since the pilot test area is mostly covered by grass and sparging will occur at depth, accumulation of sparged vapor in aboveground structures is considered unlikely, although monitoring would be performed for verification purposes.

COST

For the purpose of developing a cost estimate, it was assumed that the system would operate on a cycle of 1 hour on - 23 hours off (total "on" time seven hours per week), at a flow rate of 200 cfm (5% nutrient gas and 95% air). The use of propane was assumed, since it is less expensive than methane. The increased volume of sparge gas injected per week and the increased capital and operational costs associated with air handling equipment (i.e. air compressor or blower) offsets decreased unit cost of the gas, relative to injection of hydrogen. The cost of a co-metabolic sparge pilot test is estimated to be $712,000. Of this cost, $570,000 is required for the installation of the system and $142,000 is required for operation and monitoring. The cost estimate included in Appendix A is budgetary. The time frame for the field demonstration was assumed to be one year. Literature review (ESTCP, 2001; DOE, 1997), indicates that one year of operation should be sufficient to achieve significant source reduction. If greater mass removal appears to be achievable, the system could be operated for a greater length of time.

4.2.2.4 Ozone Sparging

GENERAL DESCRIPTION

Ozone is a strong oxidant, second only to fluorine and the hydroxyl radical in oxidation potential, and slightly more powerful than hydrogen peroxide. For an ozone sparge treatment system, the ozone is typically produced on-site using an ozone generator. The ozone is injected at a ratio of approximately 5% by weight in air.

EFFECTIVENESS

Ozone can reduce chlorinated solvent concentrations within a very short period of time, provided conditions are favorable for delivering the ozone to the solvent (i.e. relatively homogeneous and highly permeable aquifer or soil). Since ozone reacts quickly and degrades into harmless molecular oxygen, there is little possibility of fugitive gas accumulation or production of by-products. The oxygen produced by ozone decomposition also benefits the aerobic biodegradation of DCE and vinyl chloride (Newell, 1999).

IMPLEMENTABILITY

Ozone is an unstable molecule, with a half-life of approximately two minutes in air and 20 minutes dissolved in water. This characteristic could be considered both a drawback and a benefit, depending on subsurface characteristics. Since the persistence of ozone in the environment is short, it must be delivered to the treatment area quickly and efficiently; residual oxidation potential within several hours of delivery is generally negligible. Sparging, especially using horizontal wells, is considered the fastest method to introduce ozone, in terms of an in-situ remediation process.

Ozone sparging is performed at low flow rates, in order to minimize volatilization of contaminants and to maximize ozone retention time. Because ozone is a non-selective oxidant, high organic carbon (oxidant demand) in the aquifer can delay the onset of ozone saturation conditions. For this reason, ozone sparging is typically conducted on a continuous basis for the first several months of operation, until saturation conditions (approximately 100-200 mg/L in groundwater) are achieved. Subsequently, the system is operated on a pulsed basis (thereby reducing operational costs) in order to oxidize residual TCE, and to promote aerobic biodegradation of DCE and vinyl chloride (Resource Control Corporation, 2000).

Based on conversations with professionals involved in the wastewater treatment industry, the durability of ozone generators has increased dramatically over the past decade, while capital costs have decreased. However, ozone generation equipment is moderately maintenance intensive and requires, at minimum, weekly inspection.

Although PVC is not especially well suited (compatible) with ozone, it is sufficiently durable for a short-term pilot study. High resistance materials, such as PTFE (Teflon), passivated stainless steel, PVDF (polyvinylidene fluoride) and ECTFE (ethylene chlorotrifluoroethylene) are considered cost prohibitive.

COST

The cost for an ozone sparge pilot test is estimated to be $710,000. The cost estimate included in Appendix A is budgetary. Of this cost, $558,000 is required for the installation of the system and $152,000 is required for operation and monitoring. For the purpose of the cost estimate, it was assumed that a 14-lb/day ozone generator with auxiliary blower would be rented and operated for a period of one year. The time frame for the field demonstration was assumed to be one year. Field case studies (Resource Control Corporation, 2000) indicate one year of operation should be sufficient to achieve interim remedial goals.

5.0 Comparison of Technologies

Based on the results of this technology evaluation, three potential options for a pilot study at Site 86 were developed. All three options rely on a horizontal well for substrate delivery. Use of a horizontal well is expected to significantly enhance effectiveness for any one of these technologies, relative to vertical wells or borings. Therefore, once the well is completed, more than one of these gas injection technologies could be pilot tested, and for varying periods of time. The flexibility offered by a horizontal well is an important benefit to determining the best remediation technology. It should be noted that the installation of the horizontal well accounts for approximately half of capital costs.

Technologies were evaluated for effectiveness, implementability, and cost of installation and one year of operation. A higher score indicates the technology is more likely to achieve the test objectives. Note that cost was not used to estimate effectiveness. Details of the cost estimates are provided in Appendix A.

Option	Effectiveness	Implementability	Total Cost
1 – Hydrogen Sparge	4	3	$630,000
2 - Cometabolic Sparging	4	3	$712,000
3 – Ozone Sparging	5	3	$710,000

The three technologies are considered evenly matched in terms of implementability. Gas sparging equipment is generally more reliable, less maintenance intensive and less expensive than liquid injection/extraction equipment counterparts. The implementability of hydrogen and co-metabolic (propane) sparging are hindered by potential health and safety concerns, because of possible gas accumulation within buildings (although unlikely). Such concerns are lessened by the depth of sparging (at least 50 feet bgs) and the location of the target zone, primarily in an open grass field. Ambient air and interior hydrogen and/or propane gas monitoring would be performed if either technology were selected. Monitoring data would be used to determine potential for accumulation in nearby buildings if the technology is applied full scale. Ozone sparging requires relatively intensive operation and maintenance.

Hydrogen sparging is the least expensive of the three options, since the equipment requirements, as well as operation and maintenance of that equipment, are minimal. Blowers/compressors, air handling/blending equipment, and/or ozone generators are not needed for hydrogen sparging.

Ozone sparging is considered to have the greatest potential for short-term effectiveness because oxidation of the contaminants is rapid. Bioremediation typically involves a "lag" phase, during which time the native consortium of microorganisms must adapt to the changing environment created by injection of substrates, as in the case of hydrogen and cometabolic sparging.

6.0 Predictive Modeling for Natural Attenuation

6.1 Purpose and Objectives

BIOCHLOR (Aziz, 2001) is a screening tool that simulates remediation by natural attenuation at sites contaminated with chlorinated solvents. The model attempts to predict the maximum extent of dissolved-phase plume migration over time based on a known source area and actual or assumed site conditions. The maximum extent of plume migration is estimated both as solute transport without decay and as solute transport with biotransformation modeled as a sequential first-order decay process (reductive dechlorination). The model can then be used to compare the estimated plume migration to the location of potential receptors to determine if natural attenuation will remediate groundwater prior to impact, or to estimate the distance to a point of compliance. BIOCHLOR was used to estimate the reductive dechlorination of TCE and its daughter products over time given different source configurations. The model assumes a one-dimensional flow regime with three-dimensional dispersion.

The BIOCHLOR model does not account for specific types of remediation, so assumptions as to the results of particular remedial efforts are used as inputs. This type of evaluation is helpful in determining the level to remediate groundwater in the most contaminated areas of the site (hot spots) while leaving the remainder to naturally attenuate. The downgradient hot spot area at Site 86 contains TCE at 3,758 µg/L. Assuming the hot spot is remediated to practicable concentrations, natural attenuation processes may be able to remediate the remaining dissolved concentrations to NC groundwater standards within a reasonable timeframe and within an acceptable distance from the source area.

BIOCHLOR is not a fate and transport model, but a screening tool used to determine if remediation by natural attenuation is feasible at a site. Due to the assumptive nature of the modeling scenarios, the success of any single or combination of remedial approaches described in the following sections cannot be implied nor guaranteed. The results should be viewed qualitatively and any conclusions drawn carefully.

6.2 Methodology

The objective of this modeling effort is to estimate a period of time required for the plume to reach steady state, and to estimate the maximum extent of dissolved-phase plume migration under steady state conditions. This information will allow the user to estimate the location of a point of compliance (distance required to reach the 2L Standards) under different combinations of active and passive remediation scenarios. A conservative approach was taken by assuming a constant source concentration for each remedial scenario and using maximum concentrations as inputs. Several input parameters were assumed to be the same as those presented earlier in this report. However, the majority of the input parameters (including dispersion and adsorption parameters) were estimated using BIOCHLOR commonly used values. The basic input parameters for BIOCHLOR 2.2 that were used in this modeling effort are contained in Appendix B.

Four scenarios of remedial action were modeled.

1) No action
2) 50% reduction in the source zone from treatment
3) 75% reduction in the source zone from treatment
4) 90% reduction in the source zone from treatment

6.3 Assumptions

The following input parameters were assumed using BIOCHLOR commonly used values while modeling Site 86: Seepage velocity, adsorption components, and source zone options. Seepage velocity was calculated by BIOCHLOR, resulting in a seepage velocity of 315 ft/yr. All components in the adsorption input section, including soil bulk density, fraction of organic carbon, and constituent partition coefficients, were assumed using either BIOCHLOR commonly used values or literature values. Although a continuous source is not expected to exist at Site 86, the continuous source option was selected as an input parameter due to the lack of analytical data showing source-zone reductions over time. Using the continuous source option will result in a more conservative estimation of plume migration. Decay coefficients were assumed, based on the average of a range of published valued cited by BIOCHLOR.

6.4 Results

BIOCHLOR was run under four scenarios using a modeled area length of 3000 feet. Scenario 1, no remedial action in the source zone, estimates that the plume will reach steady state conditions after approximately 21 years and TCE concentrations above the 2L standards will extend approximately 2,600 feet from the source area. Scenario 4, 90% reduction of the source zone concentrations, estimates that the plume will reach steady state conditions after approximately 12 years and concentrations of all chlorinated solvents other than TCE will be below the 2L Standards within 1,400 feet of the source zone. The results of the modeled scenarios are summarized in Table 6-1. The input and output associated with the scenarios is presented in Appendix B. Stick Creek, the nearest potential surface water receptor, is located approximately 1,400 feet downgradient of the "hot spot" area.

TABLE 6-1
Biochlor Modeling Results

Scenario	Source Reduction (treatment efficiency)	Time to Steady State (years)	Distance to 2L Standard (ft)			
			PCE (0.7 μg/L)	TCE (2.8 μg/L)	DCE (70 μg/L)	VC (0.015 μg/L)
1	No treatment	21	N/A	2,600	350	2,300
2	50%	15	N/A	2,300	200	2,000
3	75%	15	N/A	1,800	0	1,600
4	90%	12	N/A	1,400	0	1,200

Distance from source area to creek is approximately 1,300 ft

Based on results of the BIOCHLOR modeling, "hot spot" remediation activity at Site 86 will mitigate continued off-site mitigation of the contaminant plume.

7.0 Recommendations

Based on the comparison of technologies summarized in the previous section, ozone sparging is considered to have the greatest potential for success and is recommended as the preferred technology for implementation at Site 86. The total cost associated with ozone sparging is approximately 10% greater than that of the least expensive alternative (hydrogen sparging). However, ozone sparging offers the following benefits:

1) rapid oxidation of the chlorinated solvent compounds of concern;
2) elimination of the "lag" phase, common to biodegradation;
3) absence of insoluble precipitates, common to other advanced oxidation technologies;
4) increase in dissolved oxygen concentrations, supportive of aerobic biodegradation for low molecular weight solvent compounds, such as DCE and VC;
5) negligible risk associated with accumulation of potentially dangerous gases in buildings or enclosures at the surface; and,
6) proven effectiveness and reliability in the wastewater treatment industry.

The recommended approach for implementation of ozone sparging at Site 86 is to use an approximately 400 foot long directionally drilled horizontal well. The horizontal well would be designed to deliver ozone to the "hot spot" area of the plume exceeding 200 μg/L TCE in groundwater, located approximately 700 feet downgradient of the southeast corner of the site. The well screen would be constructed of high-density polyethylene (HDPE) piping, including a specially designed (non-uniform) slot configuration. The ozone generator and compressor equipment would be rented for a period of one year and maintained in a fully enclosed, mobile trailer on-site.

After the one year period (or less) of pilot test operation, a decision will be made to continue operation, discontinue the test, or evaluate a different sparge technology, such as hydrogen or co-metabolic. Based on the results of pilot test, horizontal well sparging technology may be applied to other areas of the Site 86 plume.

8.0 References

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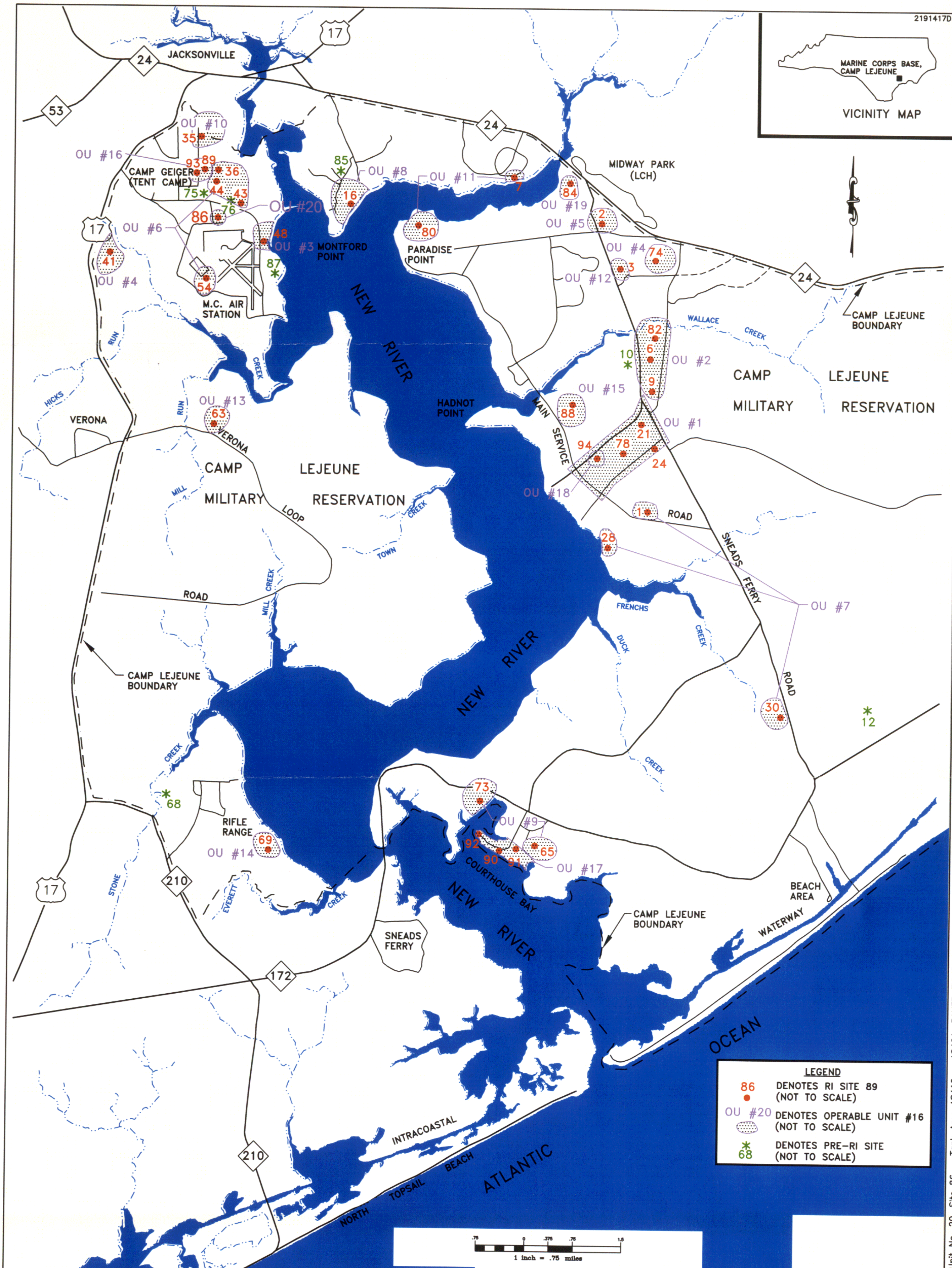
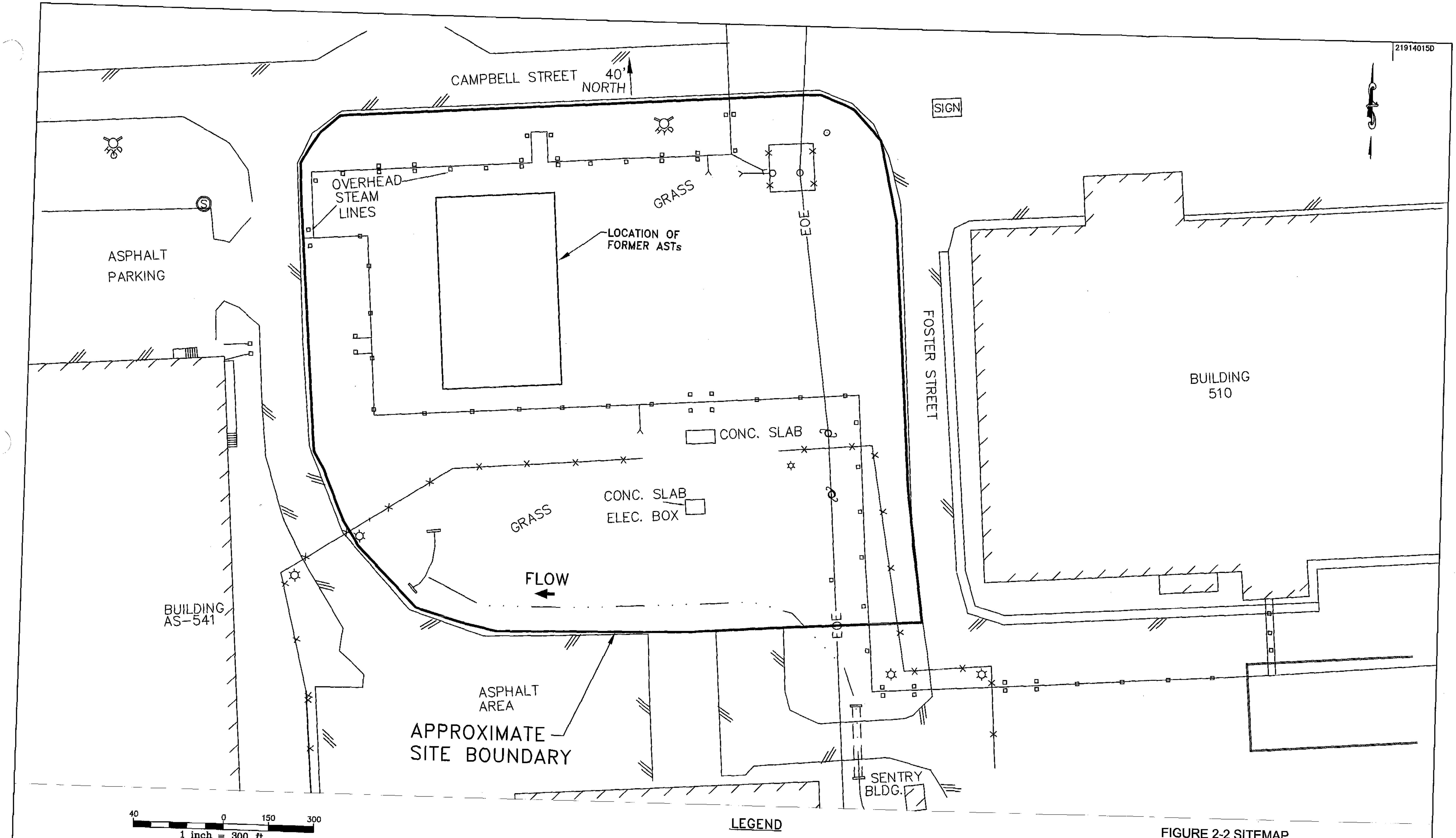


SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

FIGURE 2-1
OPERABLE UNIT AND SITE LOCATION MAP
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

CH2MHILL



LEGEND

ASPHALT ROAD
FENCE
OVERHEAD ELECTRIC LINE & UTILITY POLE

FIGURE 2-2 SITEMAP
SITE ASSESSMENT SAMPLING LOCATIONS
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

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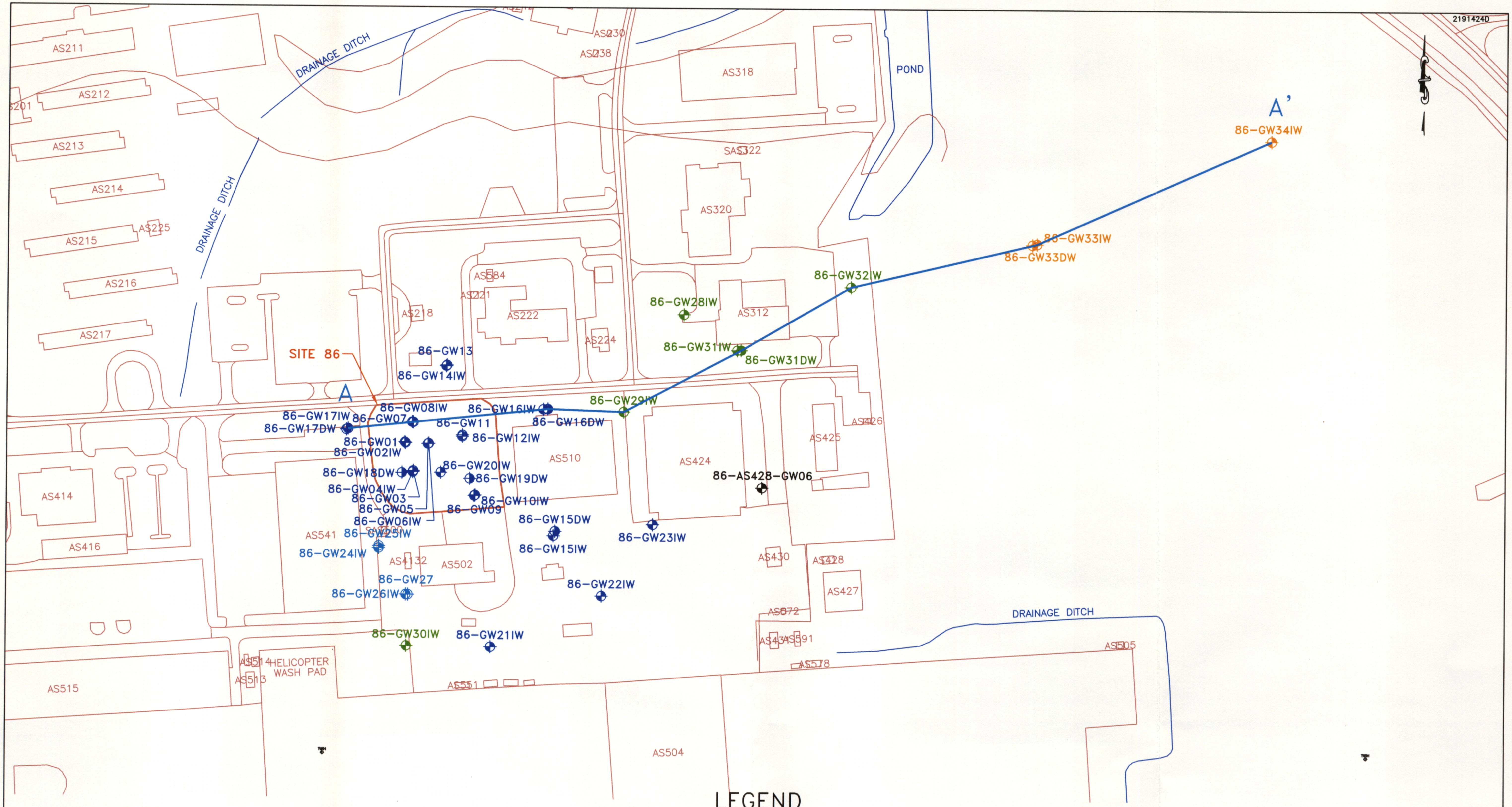

LEGEND

- SHALLOW MONITORING WELL (RI – 1995)
- INTERMEDIATE MONITORING WELL (UST PROGRAM)
- INTERMEDIATE MONITORING WELL (RI – 1995)
- INTERMEDIATE MONITORING WELL (POST RI – 1997)
- INTERMEDIATE MONITORING WELL (AMENDED RI – 2002)
- DEEP MONITORING WELL (RI – 1995)
- DEEP MONITORING WELL (POST RI – 1995)
- DEEP MONITORING WELL (POST RI – 1997)
- DEEP MONITORING WELL (AMENDED RI – 2002)

200 0 100 200

1 inch = 200 ft.

FIGURE 2-3
REVISED CROSS SECTION A-A'
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

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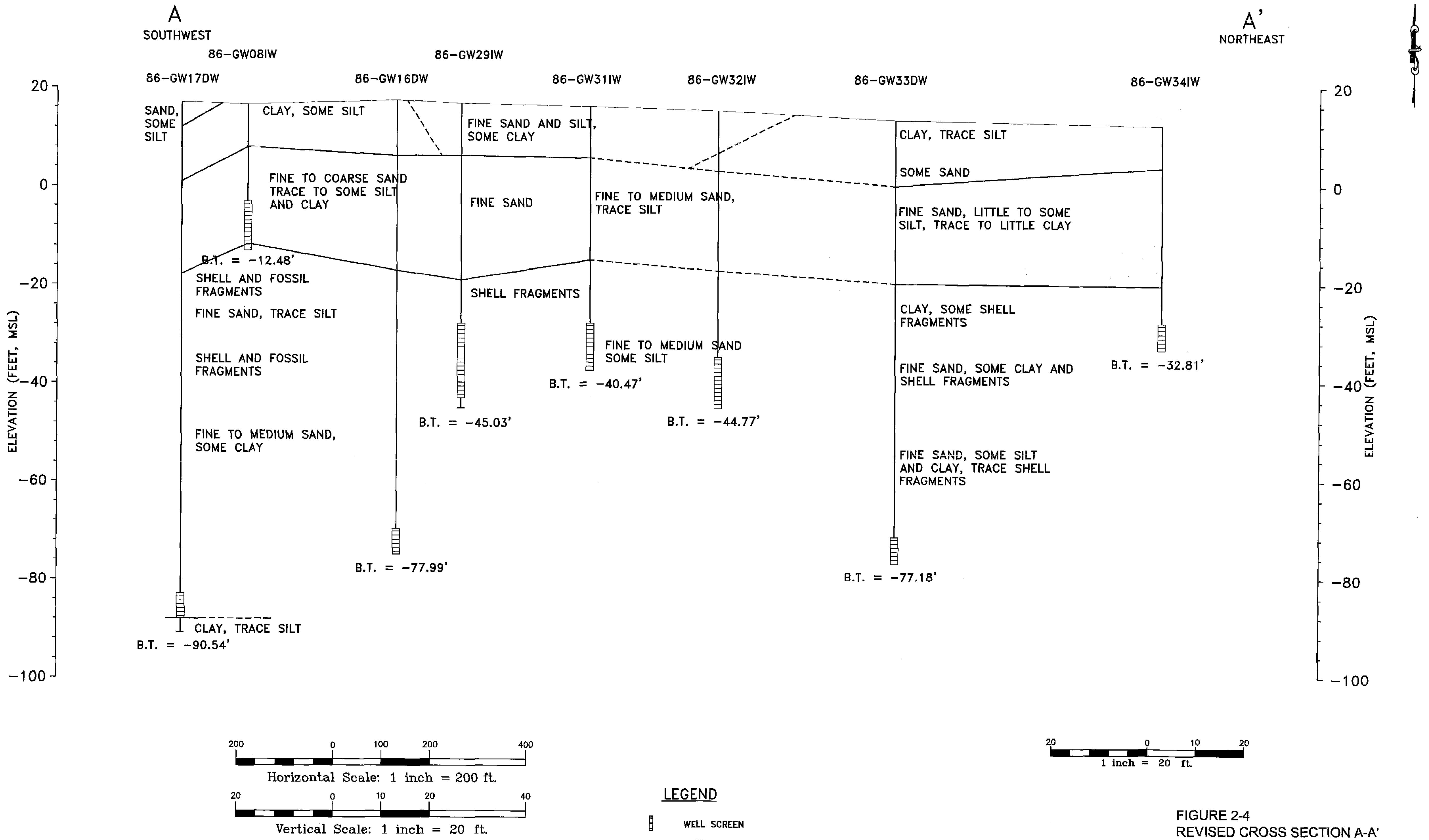

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

LEGEND

	WELL SCREEN
———	ESTIMATED CONTACT
- - - - -	INTERPOLATED CONTACT
B.T.	BORING TERMINATION (ELEVATION)

FIGURE 2-4
REVISED CROSS SECTION A-A'
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 - Tank Area AS419 - AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

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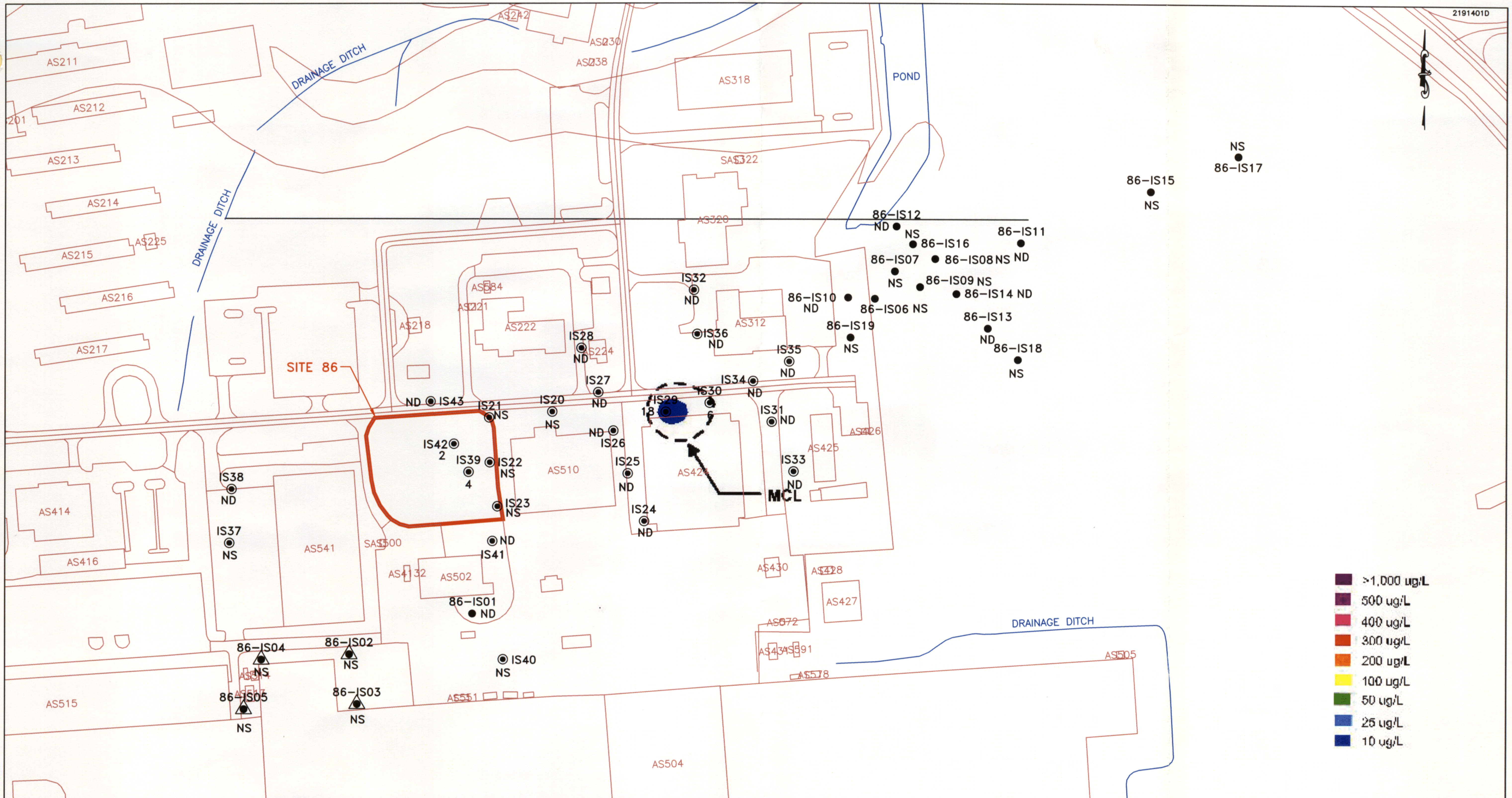

LEGEND

- ● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
- ▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
- ◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
- ND – COMPOUND NOT DETECTED
- NS – INTERVAL NOT SAMPLED

200 0 100 200
1 inch = 200 ft.

FIGURE 2-5
EXTENT OF PCE ABOVE THE DETECTION LIMIT (30 TO 34 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

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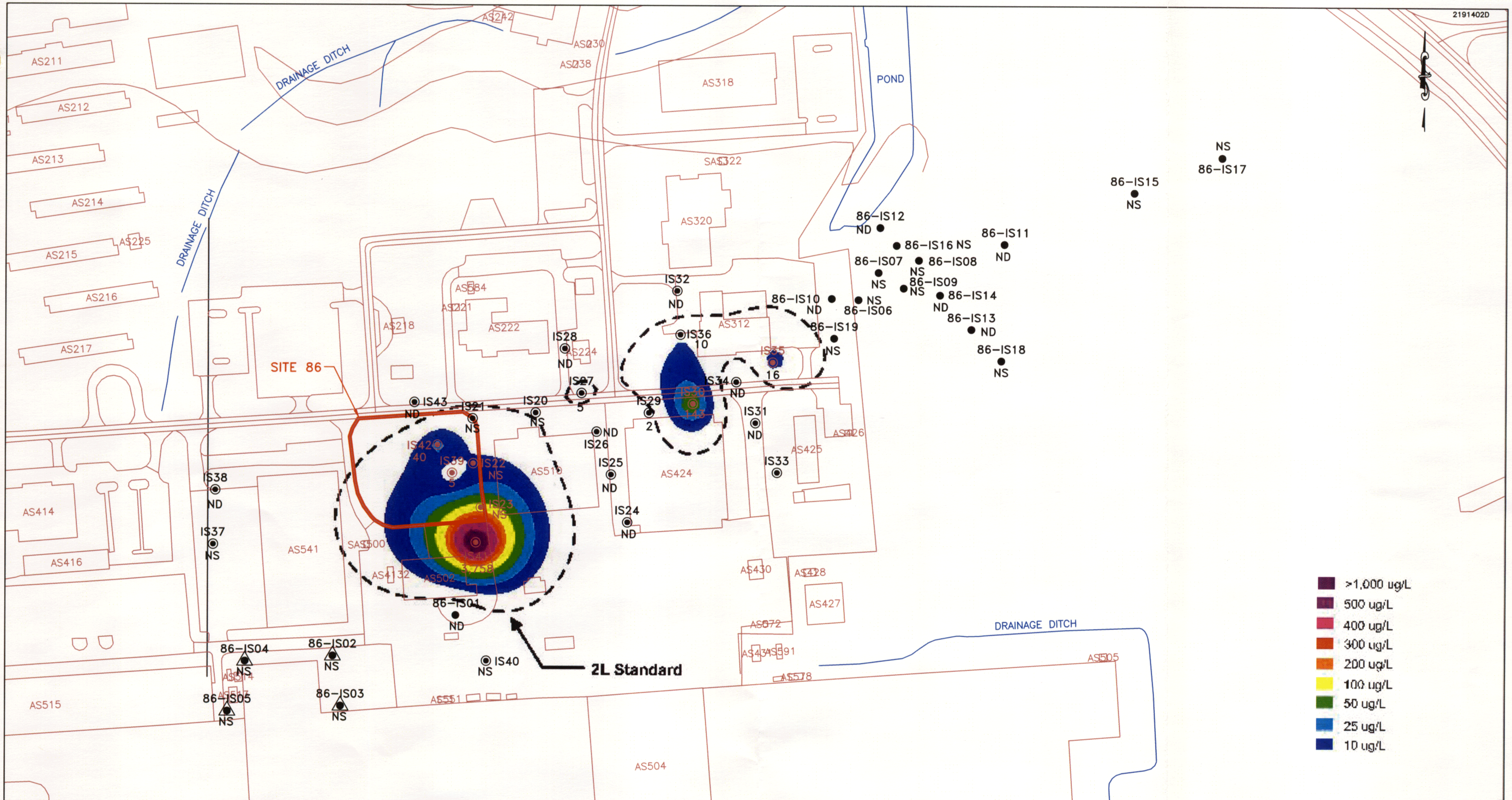
SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.



LEGEND

● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION

▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION

◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION

ND – COMPOUND NOT DETECTED

NS – INTERVAL NOT SAMPLED

200 0 100 200

1 inch = 200 ft.

FIGURE 2-6
EXTENT OF TCE ABOVE THE 2L STANDARD (30 TO 34 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

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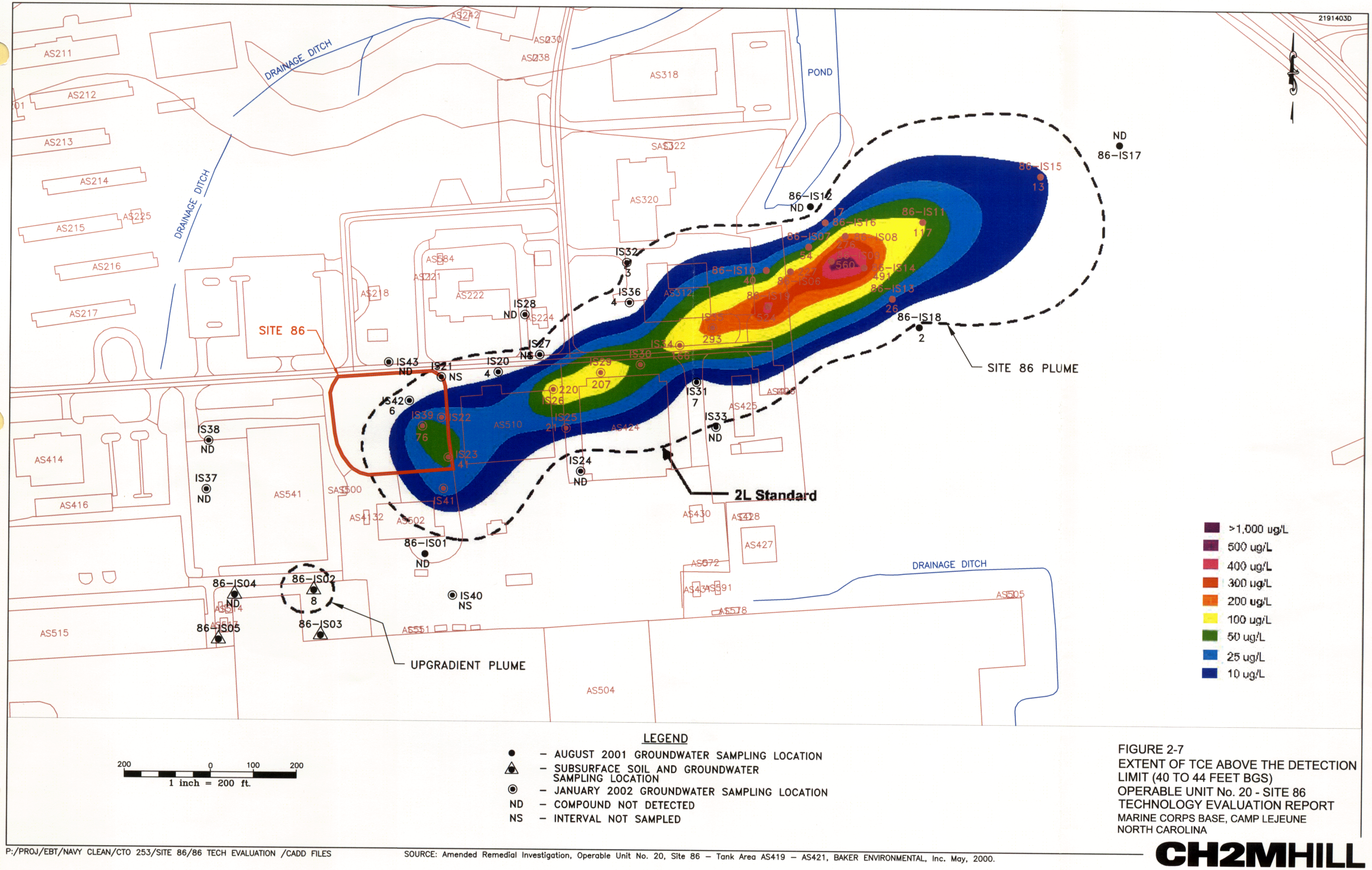
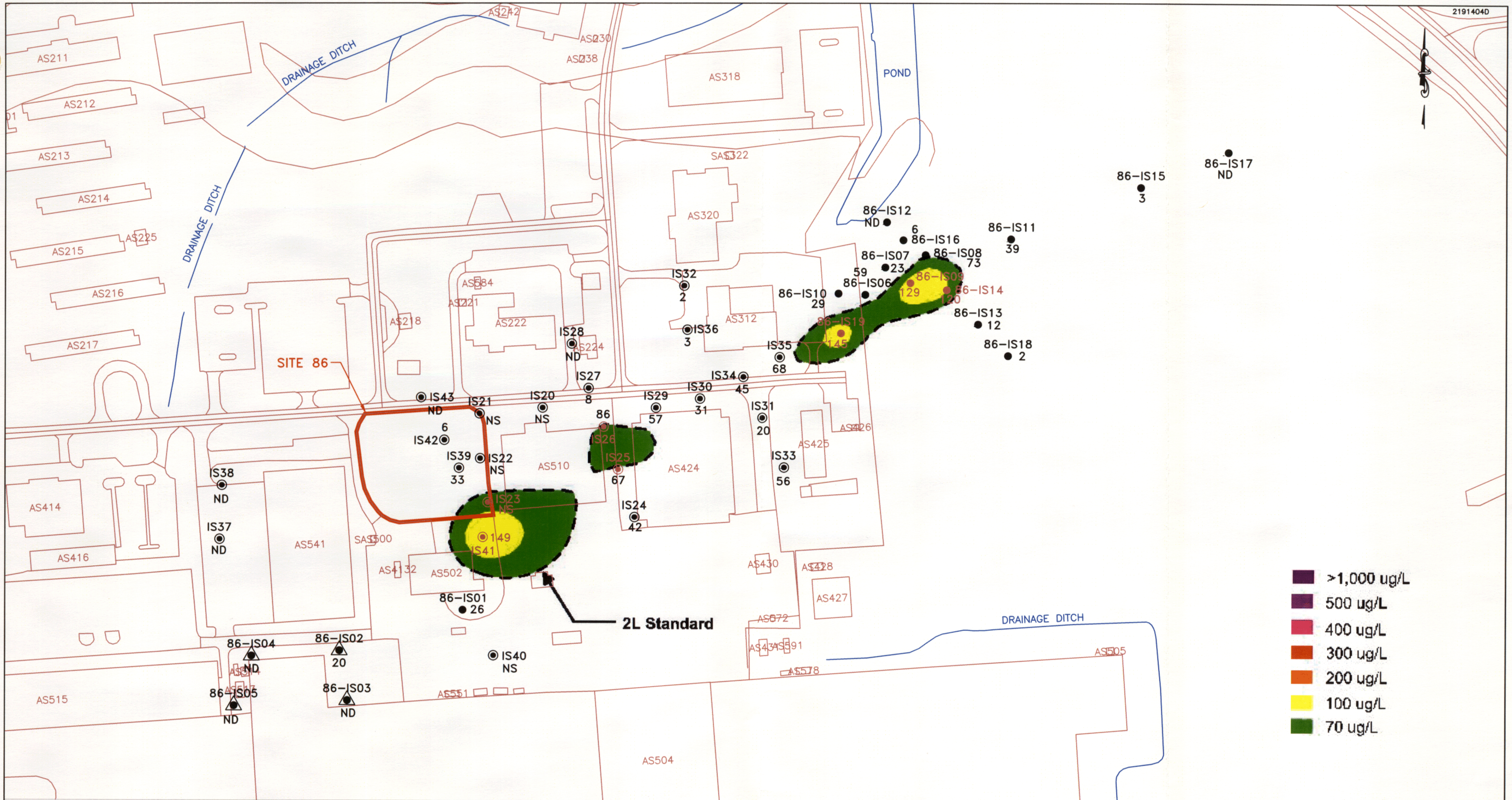


2191403D
DRAINAGE DITCH
POND
SITE 86
SITE 86 PLUME
2L Standard
UPGRADIENT PLUME
86-IS17
ND
86-IS15
13
86-IS12
ND
86-IS11
117
86-IS16
17
86-IS07
54
86-IS08
560
86-IS14
491
86-IS10
40
86-IS13
26
86-IS18
2
IS32
3
IS36
4
IS28
ND
IS27
NS
IS43
ND
IS21
NS
IS20
4
IS34
166
293
IS29
207
IS30
IS26
220
IS25
21
IS31
7
IS33
ND
IS42
6
IS39
76
IS22
IS23
41
IS41
IS24
ND
IS38
ND
IS37
ND
86-IS01
ND
86-IS02
8
86-IS03
86-IS04
ND
86-IS05
IS40
NS
>1,000 ug/L
500 ug/L
400 ug/L
300 ug/L
200 ug/L
100 ug/L
50 ug/L
25 ug/L
10 ug/L
200 0 100 200
1 inch = 200 ft.
LEGEND
● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
ND – COMPOUND NOT DETECTED
NS – INTERVAL NOT SAMPLED
FIGURE 2-7
EXTENT OF TCE ABOVE THE DETECTION LIMIT (40 TO 44 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA
CH2MHILL
P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES
SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.



LEGEND

- ● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
- ▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
- ◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
- ND – COMPOUND NOT DETECTED
- NS – INTERVAL NOT SAMPLED

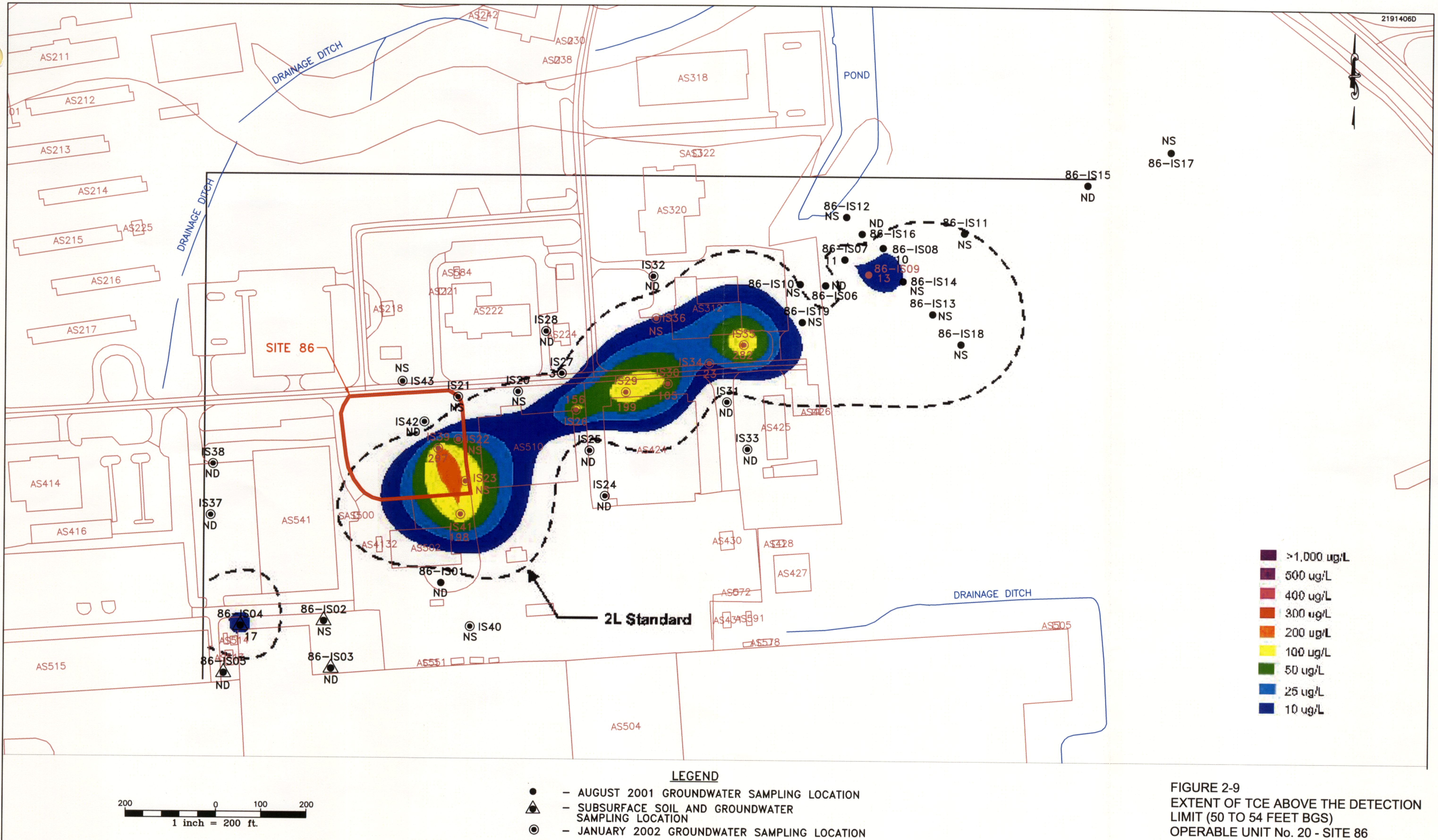
200 0 100 200
1 inch = 200 ft.

FIGURE 2-8
EXTENT OF CIS-DCE ABOVE THE DETECTION LIMIT (40 TO 44 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.



LEGEND

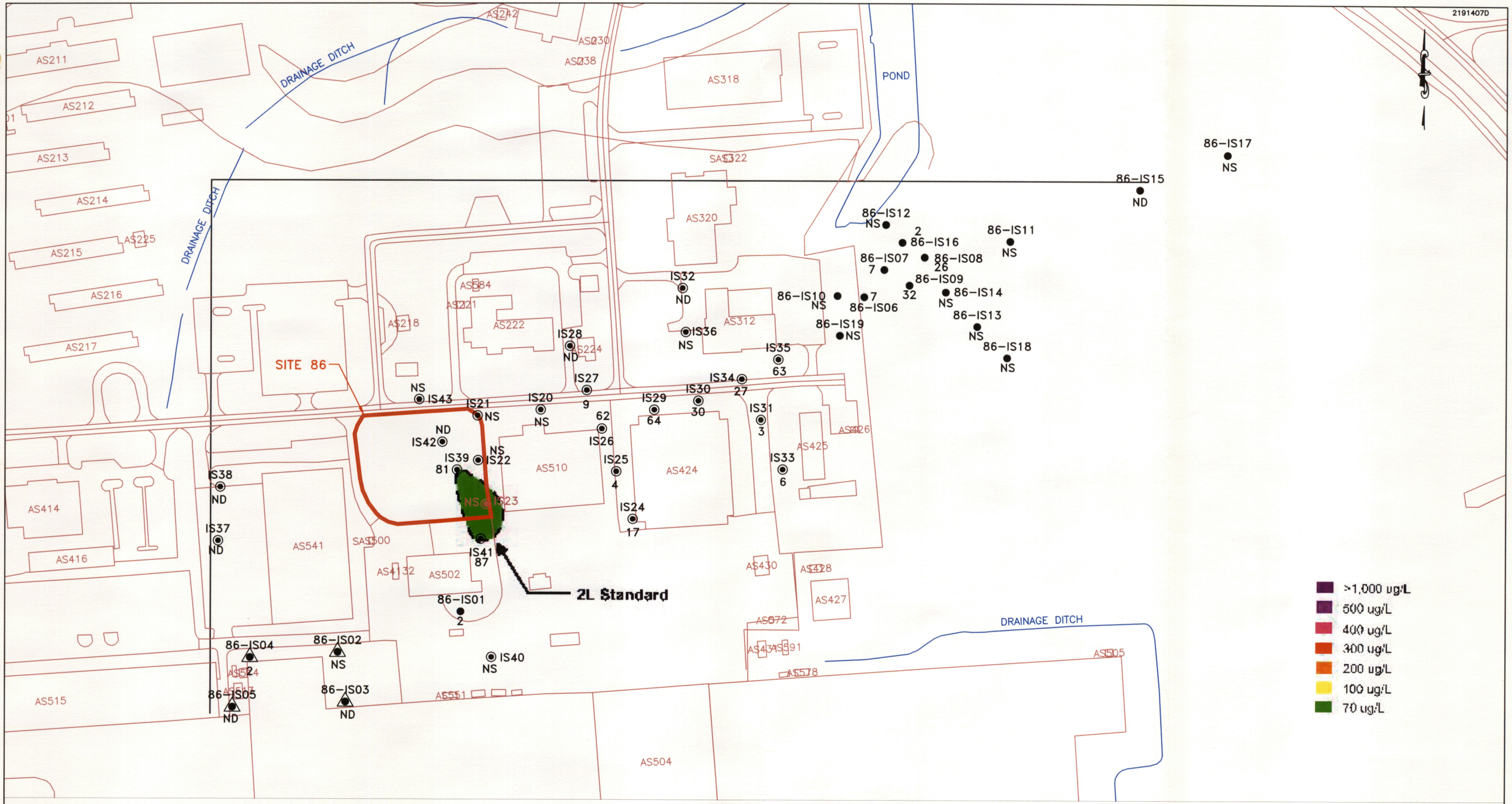
- ● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
- ▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
- ◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
- ND – COMPOUND NOT DETECTED
- NS – INTERVAL NOT SAMPLED

FIGURE 2-9
EXTENT OF TCE ABOVE THE DETECTION LIMIT (50 TO 54 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

CH2MHILL



200 0 100 200
1 inch = 200 ft.

LEGEND

- ● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
- ▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
- ◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
- ND – COMPOUND NOT DETECTED
- NS – INTERVAL NOT SAMPLED

FIGURE 2-10
EXTENT OF CIS-DCE ABOVE THE DETECTION LIMIT (50 TO 54 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

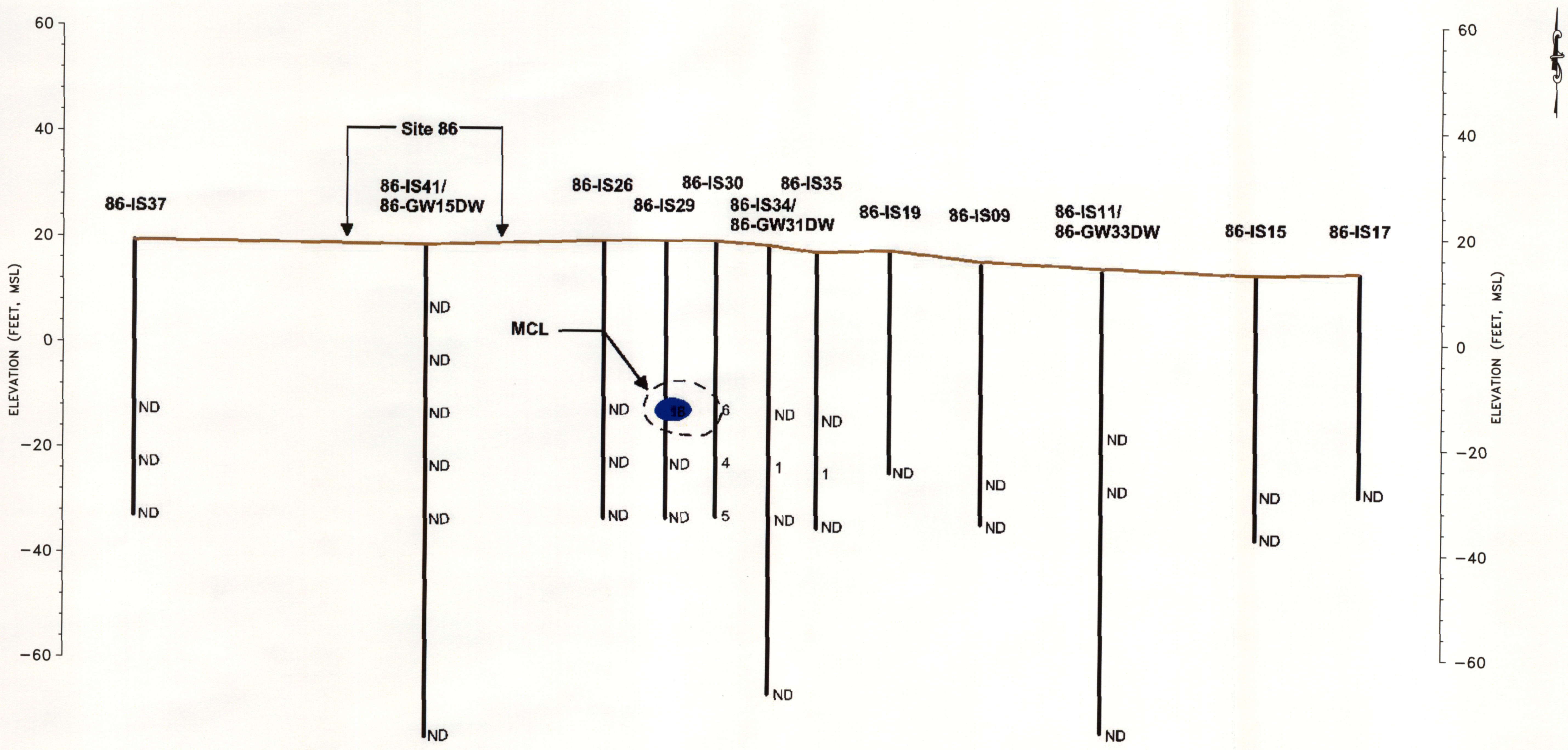
SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

CH2MHILL

A
SOUTHWEST

A
NORTHEAST

2191419W



>1,000 ug/L
500 ug/L
400 ug/L
300 ug/L
200 ug/L
100 ug/L
50 ug/L
25 ug/L
10 ug/L

200 0 100 200 400
Horizontal Scale: 1 inch = 200 ft.

20 0 10 20 40
Vertical Scale: 1 inch = 20 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

LEGEND

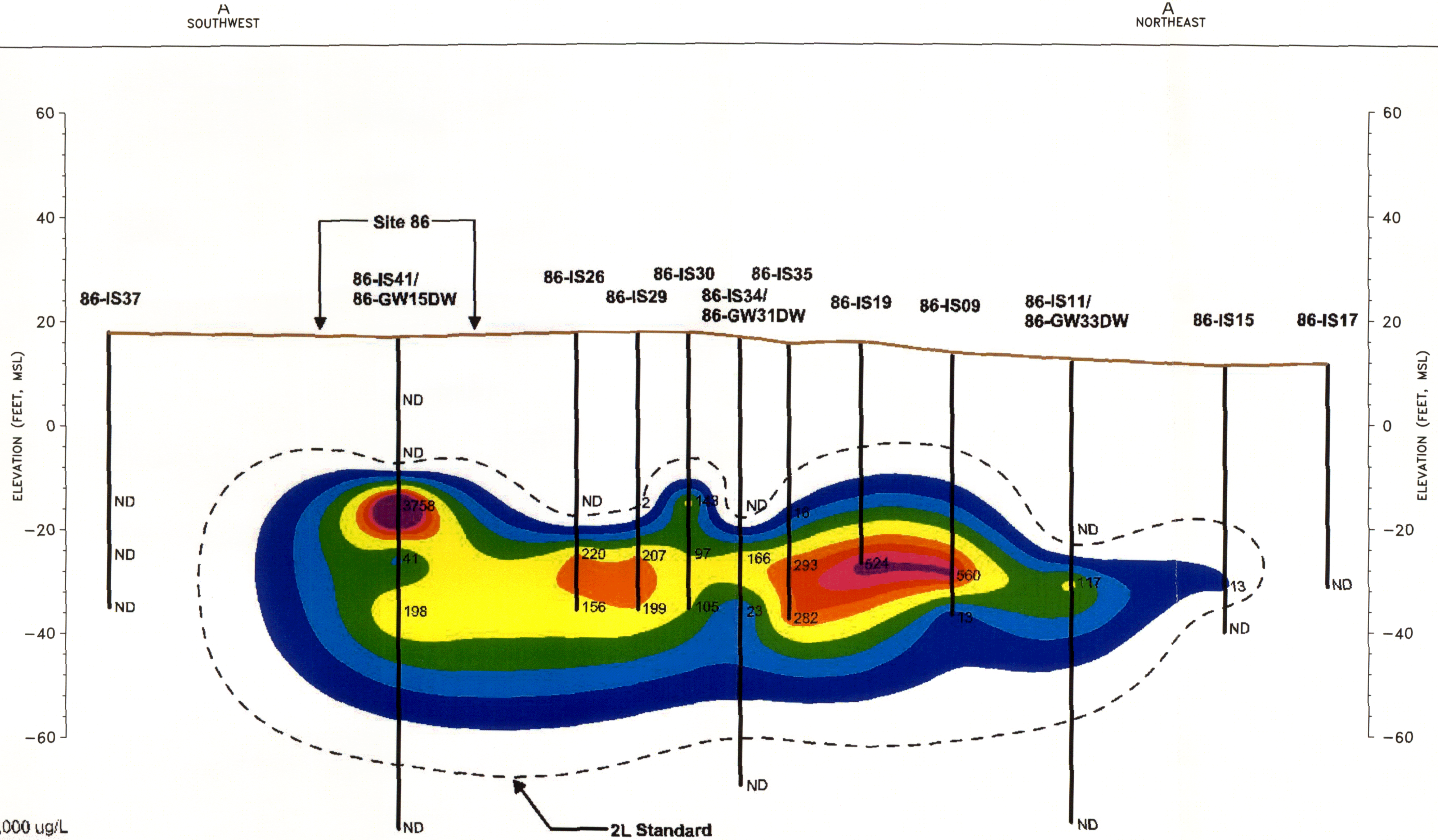
CONCENTRATIONS EXPRESSED IN ug/L
ND – COMPOUND NOT DETECTED
NS – INTERVAL NOT SAMPLED

FIGURE 2-11
PCE CROSS SECTION
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

CH2MHILL



>1,000 ug/L
500 ug/L
400 ug/L
300 ug/L
200 ug/L
100 ug/L
50 ug/L
25 ug/L
10 ug/L

200 0 100 200 400

Horizontal Scale: 1 inch = 200 ft.

20 0 10 20 40

Vertical Scale: 1 inch = 20 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

LEGEND

CONCENTRATIONS EXPRESSED IN ug/L

ND – COMPOUND NOT DETECTED

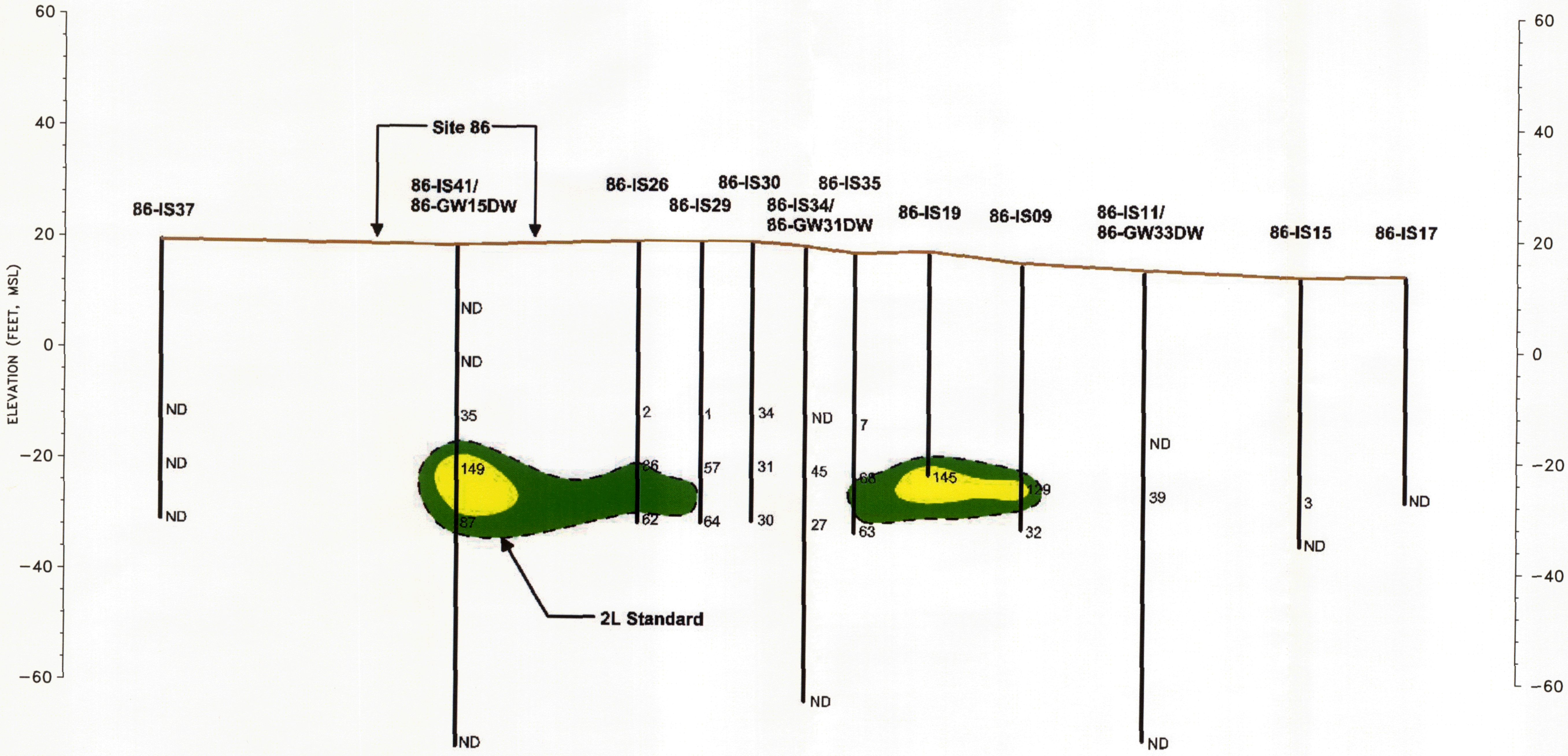
NS – INTERVAL NOT SAMPLED

FIGURE 2-12
TCE CROSS SECTION
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

CH2MHILL

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.



	>1,000 ug/L
	500 ug/L
	400 ug/L
	300 ug/L
	200 ug/L
	100 ug/L
	70 ug/L

Horizontal Scale: 1 inch = 200 ft.

Vertical Scale: 1 inch = 20 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

LEGEND

CONCENTRATIONS EXPRESSED IN ug/L

ND – COMPOUND NOT DETECTED

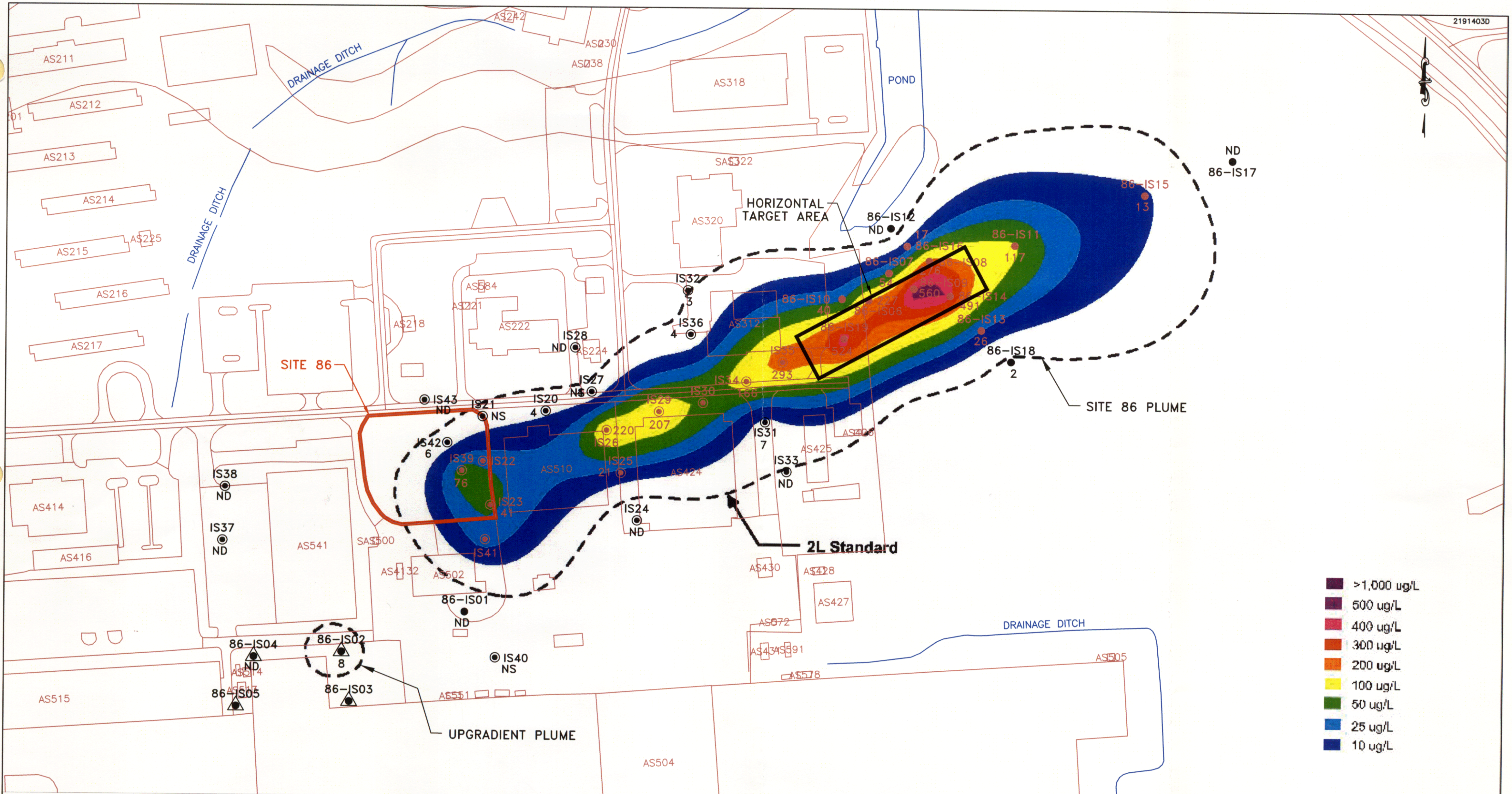
NS – INTERVAL NOT SAMPLED

FIGURE 2-13
DCE CROSS SECTION
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

CH2MHILL



200 0 100 200

1 inch = 200 ft.

LEGEND

- ● – AUGUST 2001 GROUNDWATER SAMPLING LOCATION
- ▲ – SUBSURFACE SOIL AND GROUNDWATER SAMPLING LOCATION
- ◉ – JANUARY 2002 GROUNDWATER SAMPLING LOCATION
- ND – COMPOUND NOT DETECTED
- NS – INTERVAL NOT SAMPLED

FIGURE 3-1
HORIZONTAL WELL TARGET AREA
TCE PLUME (40 TO 44 FEET BGS)
OPERABLE UNIT No. 20 - SITE 86
TECHNOLOGY EVALUATION REPORT
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

P:/PROJ/EBT/NAVY CLEAN/CTO 253/SITE 86/86 TECH EVALUATION /CADD FILES

SOURCE: Amended Remedial Investigation, Operable Unit No. 20, Site 86 – Tank Area AS419 – AS421, BAKER ENVIRONMENTAL, Inc. May, 2000.

CH2MHILL

COST ESTIMATE FOR HYDROGEN SPARGING USING SINGLE HORIZONTAL WELL

SITE 86, Camp Lejeune

CH2M HILL Project No. 174057.TS.ED.86

CAPITAL COSTS

Description	Qty Unit	Unit Cost	Cost	Comments
Mobilization/Demobilization- Subcontractor				
Equipment Prep, Mobilization, Demobilization	1 LS	$70,000.00	$70,000	Based on verbal estimate by Starr Environmental
Conceptual Design Report	1 LS	$10,000.00	$10,000	Based on verbal estimate by Starr Environmental
Submittals, Work Plan, HASP	1 LS	$12,000.00	$12,000	Based on verbal estimate by Starr Environmental
Subtotal Mobilization/Demobilization			$92,000	
Construction - Subcontractor				
Monitoring Well Installation Subcontractor	10 wells	$4,200.00	$42,000	Based on verbal quote by Prosonic Drilling
Project Management and Coordination	1 LS	$12,000.00	$12,000	Based on verbal estimate by Starr Environmental
Installation of horizontal well (approximately 400 feet in length, with 500 feet of entry and exit drilling to achieve target depth; approximately 50 feet below grade)	900 ft	$180.00	$162,000	Based on verbal estimate by Starr Environmental, and Longbore Drilling Company (including decon, soil disposal, and well development)
Misc. Field Piping/Manifolding	1 LS	$5,000.00	$5,000	
Protective Enclosure	1 LS	$18,000.00	$18,000	
Hydrogen Biosparging Equipment and Installation	1 LS	$123,000.00	$123,000	Based on lump sum estimate by Groundwater Science, Inc.
Subtotal *Construction*			$362,000	
Construction - CH2M Hill				
Project Management				
Project Manager	100 hours	$71.04	$7,104	
Work Plans, Permits, Initial Reports				
Senior Engineer	8 hours	$87.61	$701	
Project Manager	40 hours	$71.04	$2,842	
Associate Engineer	100 hours	$57.69	$5,769	
Horizontal Well Drilling				
Project Manager	25 hours	$71.04	$1,776	
Associate Engineer	40 hours	$57.69	$2,308	
Field Geologist	200 hours	$43.58	$8,716	assume 20 days to install horizontal well
Monitoring Well Installation				
Project Manager	8 hours	$71.04	$568	
Associate Engineer	16 hours	$57.69	$923	
Field Geologist	100 hours	$43.58	$4,358	assume 1 day per monitoring well
Hydrogen Sparge Equipment Installation & Start-Up				
Project Manager	8 hours	$71.04	$568	
Associate Engineer	50 hours	$57.69	$2,885	
Field Geologist/tech	100 hours	$43.58	$4,358	
System De-Commissioning, Post-Sampling, and Final Report				
Senior Engineer	8 hours	$87.61	$701	
Project Manager	24 hours	$71.04	$1,705	
Associate Engineer	50 hours	$57.69	$2,885	
Field Geologist/tech	150 hours	$43.58	$6,537	
Subtotal *Professional Services*			$54,703	

COST ESTIMATE FOR HYDROGEN SPARGING USING SINGLE HORIZONTAL WELL
SITE 86, Camp Lejeune
CH2M HILL Project No. 174057.TS.ED.86

Equipment and Expenses				
Per Diem (Incl. Truck Rental)	60 days	$150.00	$9,000	
Monitoring Well Surveying	1 LS	$5,000.00	$5,000	
Misc. Sampling Equipment and Supplies	1 LS	$1,000.00	$1,000	
Subtotal *Equipment and Expenses*			$15,000	
Subtotal *Construction - CH2M HILL*			$69,703	
TOTAL CAPITAL COST			**$523,703**	

YEAR 1 OPERATIONS AND MAINTENANCE				
Item/Activity	Qty Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Baseline and 4 Events after Startup - Assume 14 Monitoring Wells)				
Sample Labor	5 event	$5,000.00	$25,000	
Sample Analysis - Subcontractor	5 event	$2,500.00	$12,500	18 samples/round incl. QA/QC
GW Sampling Equipment and Supplies	5 event	$1,000.00	$5,000	
Subtotal *Baseline Groundwater Sampling*			$42,500	
Reporting (Construction Completion Report and 5 Events Reports)				
Reporting Labor (quarterly reports)	5 rpts	$3,000.00	$15,000	
Reporting Labor (construction completion report)	1 rpt	$5,000.00	$5,000	
Subtotal *Reporting*			$20,000	
Routine System O&M				
Project Management	12 mo	$900.00	$10,800	
Technician Labor	12 mo	$2,200.00	$26,400	
O&M Supplies	1 ls	$2,000.00	$2,000	
Subtotal *Routine System O&M*			$28,400	
Consumables				
Hydrogen (4 "welding gas" type vessels, ~1000 ft3, ultra high purity grade hydrogen per week)	52 wks	$240.00	$12,480	
Cylinder rental	12 mo	$100.00	$1,200	
Electrical usage	1 year	$2,000.00	$2,000	
Subtotal *Consumables*			$15,680	
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST			**$106,580**	
TOTAL ESTIMATE OF COSTS			***$630,283***	

COST ESTIMATE FOR COMETABOLIC SPARGING USING SINGLE HORIZONTAL WELL
SITE 86, Camp Lejeune
CH2M HILL Project No. 174057.TS.ED.86

CAPITAL COSTS				
Description	Qty Unit	Unit Cost	Cost	Comments
Mobilization/Demobilization- Subcontractor				
Equipment Prep, Mobilization, Demobilization	1 LS	$70,000	$70,000	Based on verbal estimate by Starr Environmental
Conceptual Design Report	1 LS	$10,000	$10,000	Based on verbal estimate by Starr Environmental
Submittals, Work Plan, HASP	1 LS	$12,000	$12,000	Based on verbal estimate by Starr Environmental
Bench Scale Study	1 LS	$20,000	$20,000	Based on lump sum CH2M Hill estimate for similar work
Subtotal Mobilization/Demobilization			$112,000	
Construction - Subcontractor				
Monitoring Well Installation Subcontractor	10 wells	$4,200	$42,000	Based on verbal quote by Prosonic Drilling
Project Management and Coordination	1 LS	$12,000	$12,000	Based on verbal estimate by Starr Environmental
Installation of horizontal well (approximately 400 feet in length, with 500 feet of entry and exit drilling to achieve target depth; approximately 50 feet below grade)	900 ft	$180	$162,000	Based on verbal estimate by Starr Environmental, and Longbore Drilling Company (including decon, soil disposal, and well development)
Misc. Field Piping/Manifolding	1 LS	$5,000	$5,000	
Protective Enclosure	1 LS	$18,000	$18,000	
Rotary Screw Air Compressor and Control System	1 LS	$22,000	$22,000	
Gas Blending Equipment and Installation	1 LS	$128,000	$128,000	Based on lump sum estimate by Groundwater Science, Inc.
Subtotal *Construction*			$389,000	
Construction - CH2M Hill				
Professional Services				
Project Management				
Project Manager	100 hours	$71	$7,104	
Work Plans, Permits, Initial Reports				
Senior Engineer	8 hours	$88	$701	
Project Manager	40 hours	$71	$2,842	
Associate Engineer	100 hours	$58	$5,769	
Horizontal Well Drilling				
Project Manager	20 hours	$71	$1,421	
Associate Engineer	40 hours	$58	$2,308	
Field Geologist	200 hours	$44	$8,716	assume 20 days to install horizontal well
Monitoring Well Installation				
Project Manager	8 hours	$71	$568	
Associate Engineer	16 hours	$58	$923	
Field Geologist	100 hours	$44	$4,358	assume 1 day per monitoring well
Cometabolic Sparge Equipment Installation & Start-Up				
Project Manager	8 hours	$71	$568	
Associate Engineer	50 hours	$58	$2,885	
Field Geologist/tech	100 hours	$44	$4,358	
System De-Commissioning, Post-Sampling, and Final Report				
Senior Engineer	8 hours	$88	$701	
Project Manager	24 hours	$71	$1,705	
Associate Engineer	50 hours	$58	$2,885	
Field Geologist/tech	150 hours	$44	$6,537	

COST ESTIMATE FOR COMETABOLIC SPARGING USING SINGLE HORIZONTAL WELL

SITE 86, Camp Lejeune
CH2M HILL Project No. 174057.TS.ED.86

Subtotal *Professional Services*			$54,347	
Equipment and Expenses				
Per Diem (Incl. Truck Rental)	60 days	$150	$9,000	
Monitoring Well Surveying	1 LS	$5,000	$5,000	
Misc. Sampling Equipment and Supplies	1 LS	$1,000	$1,000	
Subtotal *Equipment and Expenses*			$15,000	
Subtotal *Construction - CH2M HILL*			$69,347	
TOTAL CAPITAL COST			**$570,347**	
YEAR 1 OPERATIONS AND MAINTENANCE				
Item/Activity	Qty Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Baseline and 4 events after Startup - Assume 14 Monitoring Wells)				
Sample Labor	5 event	$5,000	$25,000	
Sample Analysis - Subcontractor	5 event	$2,500	$12,500	18 samples/round incl. QA/QC
GW Sampling Equipment and supplies	5 event	$1,000	$5,000	
Subtotal *Baseline Groundwater Sampling*			$42,500	
Reporting (Construction Completion Report and Event Reports)				
Reporting Labor (quarterly reports)	5 rpts	$3,000	$15,000	
Reporting Labor (construction completion report)	1 rpt	$5,000	$5,000	
Subtotal *Reporting*			$20,000	
Routine System O&M				
Project Management	12 mo	$900	$10,800	
Technician Labor	12 mo	$2,200	$26,400	
O&M Supplies	1 ls	$2,000	$2,000	
Subtotal *Routine System O&M*			$28,400	
Consumables				
Propane (4,200 ft3, or 118 gallons of liquid high purity grade propane per week)	52 wks	$520	$27,040	
Cylinder rental	12 mo	$100	$1,200	
Electrical usage	1 year	$22,800	$22,800	Assumes $0.07/kw-hr and 50 hp compressor
Subtotal *Consumables*			$51,040	
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST			**$141,940**	
TOTAL ESTIMATE OF COSTS			***$712,287***	

COST ESTIMATE FOR OZONE SPARGING USING SINGLE HORIZONTAL WELL

SITE 86, Camp Lejeune

CH2M HILL Project No. 174057.TS.ED.86

CAPITAL COSTS

Description	Qty Unit	Unit Cost	Cost	Comments
Mobilization/Demobilization- Subcontractor				
Equipment Prep, Mobilization, Demobilization	1 LS	$70,000	$70,000	Based on verbal estimate by Starr Environmental
Conceptual Design Report	1 LS	$10,000	$10,000	Based on verbal estimate by Starr Environmental
Submittals, Work Plan, HASP	1 LS	$12,000	$12,000	Based on verbal estimate by Starr Environmental
Subtotal Mobilization/Demobilization			$92,000	
Construction - Subcontractor				
Monitoring Well Installation Subcontractor	10 wells	$4,200	$42,000	Based on verbal quote by Prosonic Drilling
Project Management and Coordination	1 LS	$22,000	$22,000	Based on verbal estimate by Starr Environmental and RCC
Installation of horizontal well (approximately 400 feet in length, with 500 feet of entry and exit drilling to achieve target depth; approximately 50 feet below grade)	900 ft	$180	$162,000	Based on verbal estimate by Starr Environmental, and Longbore Drilling Company (including decon, soil disposal, and well development)
Misc. Field Piping/Manifolding	1 LS	$5,000	$5,000	
Protective Enclosure	1 LS	$18,000	$18,000	
Ozone Sparging Equipment Rental for 1 Year	1 LS	$148,000	$148,000	Based on lump sum estimate by Resource Control Corporation
Subtotal *Construction*			$397,000	
Construction - CH2M Hill				
Professional Services				
Project Management				
Project Manager	100 hours	$71	$7,104	
Work Plans, Permits, Initial Reports				
Senior Engineer	8 hours	$88	$701	
Project Manager	40 hours	$71	$2,842	
Associate Engineer	100 hours	$58	$5,769	
Horizontal Well Drilling				
Project Manager	25 hours	$71	$1,776	
Associate Engineer	40 hours	$58	$2,308	
Field Geologist	200 hours	$44	$8,716	assume 20 days to install horizontal well
Monitoring Well Installation				
Project Manager	8 hours	$71	$568	
Associate Engineer	16 hours	$58	$923	
Field Geologist	100 hours	$44	$4,358	assume 1 day per monitoring well
Ozone Sparge Equipment Installation & Start-Up				
Project Manager	8 hours	$71	$568	
Associate Engineer	50 hours	$58	$2,885	
Field Geologist/tech	100 hours	$44	$4,358	
System De-Commissioning, Post-Sampling, and Final Report				
Senior Engineer	8 hours	$88	$701	
Project Manager	24 hours	$71	$1,705	
Associate Engineer	50 hours	$58	$2,885	

COST ESTIMATE FOR OZONE SPARGING USING SINGLE HORIZONTAL WELL

SITE 86, Camp Lejeune

CH2M HILL Project No. 174057.TS.ED.86

Field Geologist/tech	150 hours	$44	$6,537	
Subtotal *Professional Services*			$54,703	
Equipment and Expenses				
Per Diem (Incl. Truck Rental)	60 days	$150	$9,000	
Monitoring Well Surveying	1 LS	$5,000	$5,000	
Misc. Sampling Equipment and Supplies	1 LS	$1,000	$1,000	
Subtotal *Equipment and Expenses*			$15,000	
Subtotal *Construction - CH2M HILL*			$69,703	
TOTAL CAPITAL COST			**$558,703**	

YEAR 1 OPERATIONS AND MAINTENANCE				
Item/Activity	Qty Unit	Unit Cost	Cost	Comments
Groundwater Sampling (Baseline and 4 events after Startup - Assume 14 Monitoring Wells)				
Sample Labor	5 event	$5,000	$25,000	
Sample Analysis - Subcontractor	5 event	$2,500	$12,500	18 samples/round incl QA/QC
GW Sampling Equipment and Supplies	5 event	$1,000	$5,000	
Subtotal *Baseline Groundwater Sampling*			$42,500	
Reporting (Construction Completion Report and 6 Events Reports)				
Reporting Labor (quarterly reports)	5 rpts	$3,000	$15,000	
Reporting Labor (construction completion report)	1 rpt	$5,000	$5,000	
Subtotal *Reporting*			$20,000	
Routine System O&M				
Project Management	12 mo	$900	$10,800	
Technician Labor	52 weeks	$1,200	$62,400	
O&M Supplies	1 ls	$5,000	$5,000	
Subtotal *Routine System O&M*			$67,400	
Consumables				
Electrical usage	12 months	$1,800	$21,600	
Subtotal *Consumables*			$21,600	
TOTAL YEAR 1 OPERATIONS AND MAINTENANCE COST			**$151,500**	
TOTAL ESTIMATE OF COSTS			***$710,203***	

Input Parameters for BIOCHLOR 2.2

Camp Lejeune Site 86 **Input Parameter**	All	Scenario Option 1 No Action	 Option 2 50% Reduction in Source Zone Concentration	 Option 3 75% Reduction in Source Zone Concentration	 Option 4 90% Reduction in Source Zone Concentration	Assumptions
Hydraulic Conductivity (cm/sec)	0.01905					Used AVG Conductivity of 54 ft/day = .01905 cm/sec from Table 2-2 Amended RI
Hydraulic Gradient	0.004					Data from 86 RI. Shal .002-.008 ft/ft, int .003-.005, deep .002-.006 (s<30ft, i=45-65ft, d=80-95ft)
Effective Porosity	0.25					Estimated based on Site 73
Seepage Velocity (ft/yr)	315.4					Calculated by Biochlor
Dispersion Coefficient, alpha x (ft)	19.811					Calculated using Option 3. Entered plume length of 600 ft.
alpha y / alpha x	0.33					Estimated using Biochlor commonly used value
alpha z / alpha x	0.05					Estimated using Biochlor commonly used value
Soil Bulk Density (kg/L)	1.7					Estimated using Biochlor commonly used value
Fraction Organic Carbon	0.001					Estimated using Biochlor commonly used value
Koc - PCE (L/Kg)	426					Literature correlation using solubilities at 20° C
Koc - TCE (L/Kg)	130					Literature correlation using solubilities at 20° C
Koc - DCE (L/kg)	125					Literature correlation using solubilities at 20° C
Koc - VC (L/Kg)	29.6					Literature correlation using solubilities at 20° C
Koc - Ethene (L/Kg)	302					Literature correlation using solubilities at 20° C
Decay Coefficient, PCE to TCE (1/yr)						PCE is not present.
Decay Coefficient, TCE to DCE (1/yr)	0.475					Calibrated to existing plume Data
Decay Coefficient, DCE to VC (1/yr)	1.74					Calibrated to existing plume Data
Decay Coefficient, VC to Ethene (1/yr)	1.36					Calibrated to existing plume Data
Simulation Time for Calibration	1000					Number of years from earliest source data to current field data
Modeled Area Width*	350					Approximate plume width
Modeled Area Length*	3000					Approximate plume length from current source area toward surface water
Zone 1 Length*	3000					Approximate plume length from current source area toward surface water
Source Information						
Source Thickness (ft)	24					Estimated based on Site 86 RI Figure 4-10, TCE Cross Section
Source Width (ft)	270					Used Constant/Continusous source, Single Planar option
Source Concentrations (mg/L)						
TCE		0.56	0.28	0.14	0.056	2001 lab data
DCE		0.129	0.0645	0.03225	0.0129	2001 lab data
VC		0	0	0	0	2001 lab data
Ethene		0	0	0	0	2001 lab data

Scenario 1 – No Action

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2

Excel '97

Camp Lejeune
Site 86 Scn. 1

Run Name

Data Input Instructions:

115 → 1. Enter value directly....or

or 2. Calculate by filling in gray

0.02 cells. Press Enter, then C

(To restore formulas, hit "Restore Formulas" button)

Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	315.4	(ft/yr)
or			
Hydraulic Conductivity	K	1.9E-02	(cm/sec)
Hydraulic Gradient	i	0.004	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.33	(-)
(Alpha z) / (Alpha x)*	5.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R

or

Soil Bulk Density, rho	1.7	(kg/L)
FractionOrganicCarbon, foc	1.0E-3	(-)

Partition Coefficient Koc

	Koc		R	
PCE	426	(L/kg)	3.90	(-)
TCE	130	(L/kg)	1.88	(-)
DCE	125	(L/kg)	1.85	(-)
VC	30	(L/kg)	1.20	(-)
ETH	302	(L/kg)	3.05	(-)

Common R (used in model)* = 1.88

4. BIOTRANSFORMATION

-1st Order Decay Coefficient*

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.475		0.74
DCE → VC	1.740		0.64
VC → ETH	1.360		0.45

Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	1000	(yr)
Modeled Area Width*	350	(ft)
Modeled Area Length*	3000	(ft)
Zone 1 Length*	3000	(ft)
Zone 2 Length*	0	(ft)

L W

Zone 2= L - Zone 1

6. SOURCE DATA

TYPE: Continuous Single Planar

Source Options

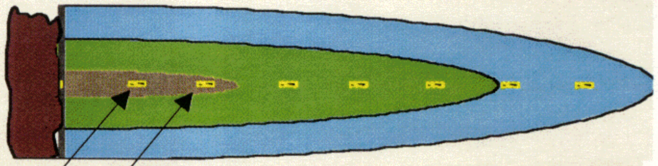
Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations

Source Thickness in Sat. Zone* 24 (ft)

Y1

Width* (ft) 270

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE	.56	0
DCE	.129	0
VC		0
ETH		0



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)											
Date Data Collected											

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

RUN ARRAY

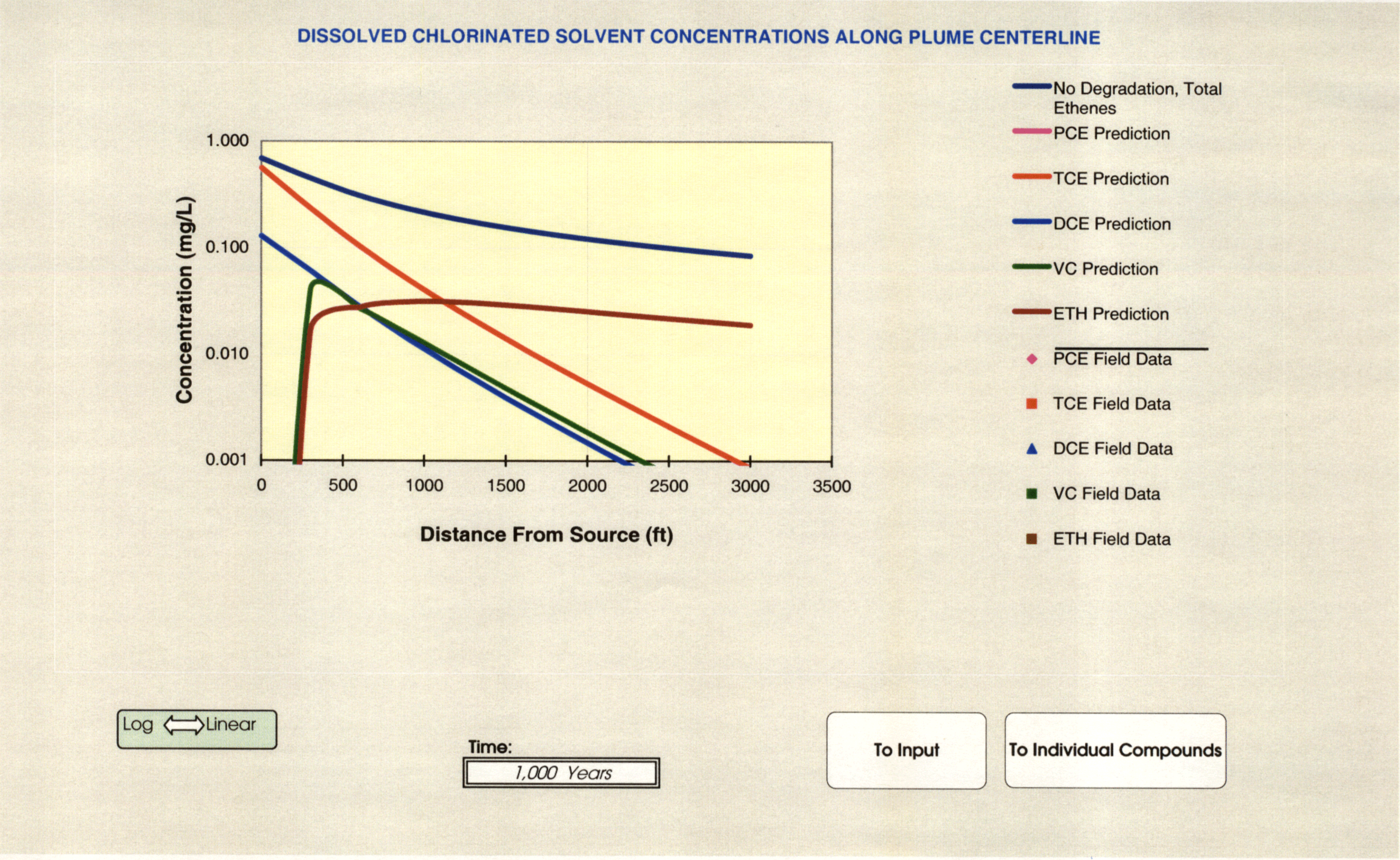
Help

Restore Formulas

RESET

SEE OUTPUT

Paste Example


DISSOLVED CHLORINATED SOLVENT CONCENTRATIONS ALONG PLUME CENTERLINE
Concentration (mg/L)
1.000
0.100
0.010
0.001
0
500
1000
1500
2000
2500
3000
3500
Distance From Source (ft)
No Degradation, Total Ethenes
PCE Prediction
TCE Prediction
DCE Prediction
VC Prediction
ETH Prediction
PCE Field Data
TCE Field Data
DCE Field Data
VC Field Data
ETH Field Data
Log
Linear
Time:
1,000 Years
To Input
To Individual Compounds

Scenario 2 – 50% reduction in the source zone from treatment

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2

Excel '97

Camp Lejeune
Site 86 Scn. 2

Run Name

Data Input Instructions:

115 → 1. Enter value directly....or

or 2. Calculate by filling in gray

0.02 cells. Press Enter, then C

(To restore formulas, hit "Restore Formulas" button)

Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	315.4	(ft/yr)
or			
Hydraulic Conductivity	K	1.9E-02	(cm/sec)
Hydraulic Gradient	i	0.004	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.33	(-)
(Alpha z) / (Alpha x)*	5.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R

or

Soil Bulk Density, rho	1.7	(kg/L)
FractionOrganicCarbon, foc	1.0E-3	(-)

Partition Coefficient	Koc		R	
PCE	426	(L/kg)	3.90	(-)
TCE	130	(L/kg)	1.88	(-)
DCE	125	(L/kg)	1.85	(-)
VC	30	(L/kg)	1.20	(-)
ETH	302	(L/kg)	3.05	(-)

Common R (used in model)* = 1.88

4. BIOTRANSFORMATION **-1st Order Decay Coefficient***

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.475		0.74
DCE → VC	1.740		0.64
VC → ETH	1.360		0.45

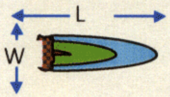
Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	1000	(yr)
Modeled Area Width*	350	(ft)
Modeled Area Length*	3000	(ft)
Zone 1 Length*	3000	(ft)
Zone 2 Length*	0	(ft)



Zone 2= L - Zone 1

6. SOURCE DATA TYPE: Continuous Single Planar

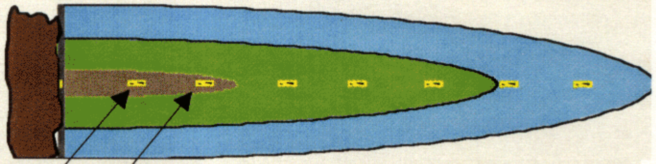
Source Options

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations

Source Thickness in Sat. Zone* 24 (ft)

	Y1
Width* (ft)	270

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE	.28	0
DCE	.065	0
VC		0
ETH		0



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)										
TCE Conc. (mg/L)										
DCE Conc. (mg/L)										
VC Conc. (mg/L)										
ETH Conc. (mg/L)										
Distance from Source (ft)										
Date Data Collected										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

RUN ARRAY

Help

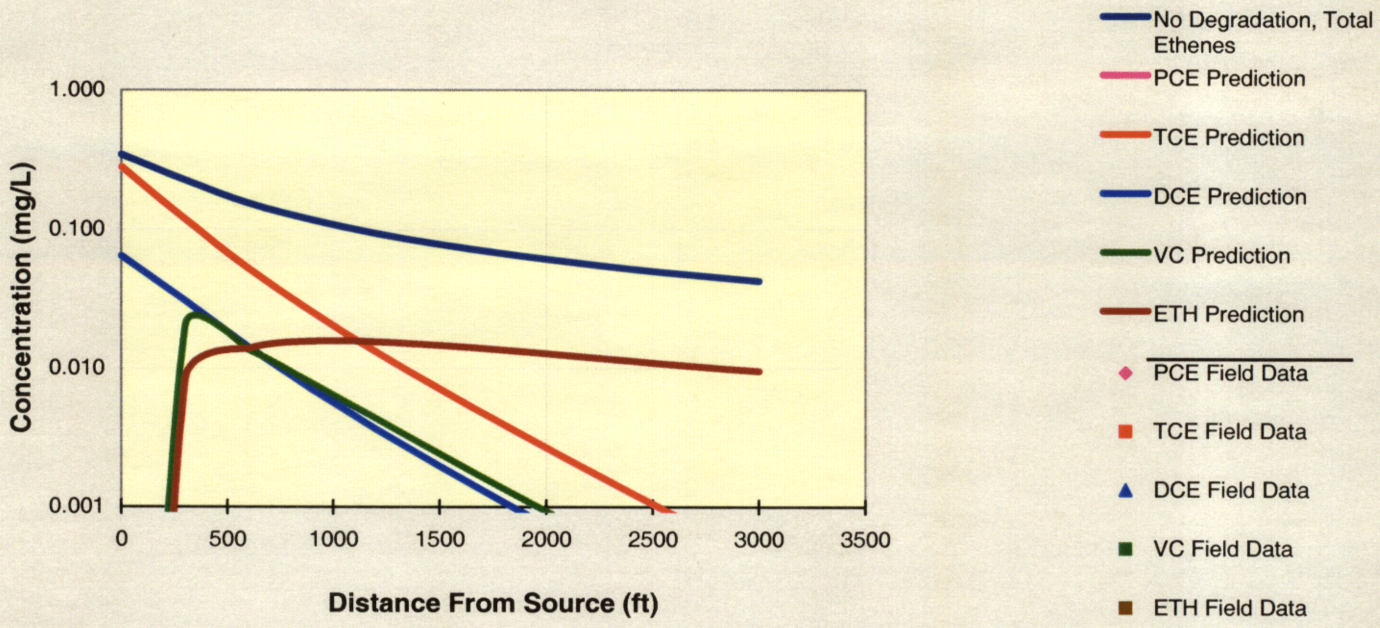
Restore Formulas

RESET

SEE OUTPUT

Paste Example

DISSOLVED CHLORINATED SOLVENT CONCENTRATIONS ALONG PLUME CENTERLINE



Log ⟺ Linear

Time:

1,000 Years

To Input

To Individual Compounds

Scenario 3 – 75% reduction in the source zone from treatment

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Run Name
Camp Lejeune
Site 86 Scn. 3

Data Input Instructions:

115 → 1. Enter value directly....or
or ↗ 2. Calculate by filling in gray
0.02 cells. Press Enter, then C
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → **Natural Attenuation Screening Protocol**

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	315.4	(ft/yr)
or			
Hydraulic Conductivity	K	1.9E-02	(cm/sec)
Hydraulic Gradient	i	0.004	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.33	(-)
(Alpha z) / (Alpha x)*	5.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R

or

Soil Bulk Density, rho	1.7	(kg/L)		
FractionOrganicCarbon, foc	1.0E-3	(-)		
Partition Coefficient	Koc			
PCE	426	(L/kg)	3.90	(-)
TCE	130	(L/kg)	1.88	(-)
DCE	125	(L/kg)	1.85	(-)
VC	30	(L/kg)	1.20	(-)
ETH	302	(L/kg)	3.05	(-)

Common R (used in model)* = 1.88

4. BIOTRANSFORMATION

-1st Order Decay Coefficient*

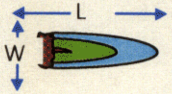
Zone 1	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.475		0.74
DCE → VC	1.740		0.64
VC → ETH	1.360		0.45

Zone 2	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	1000	(yr)
Modeled Area Width*	350	(ft)
Modeled Area Length*	3000	(ft)
Zone 1 Length*	3000	(ft)
Zone 2 Length*	0	(ft)



Zone 2= L - Zone 1

6. SOURCE DATA

TYPE: Continuous Single Planar

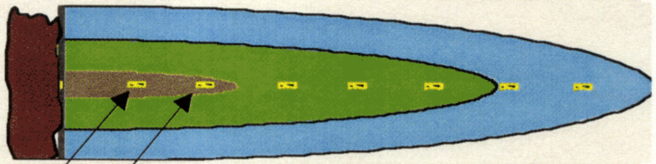
Source Options

Source Thickness in Sat. Zone* 24 (ft)

Y1
Width* (ft) 270

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE	.14	0
DCE	.032	0
VC		0
ETH		0

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations



View of Plume Looking Down

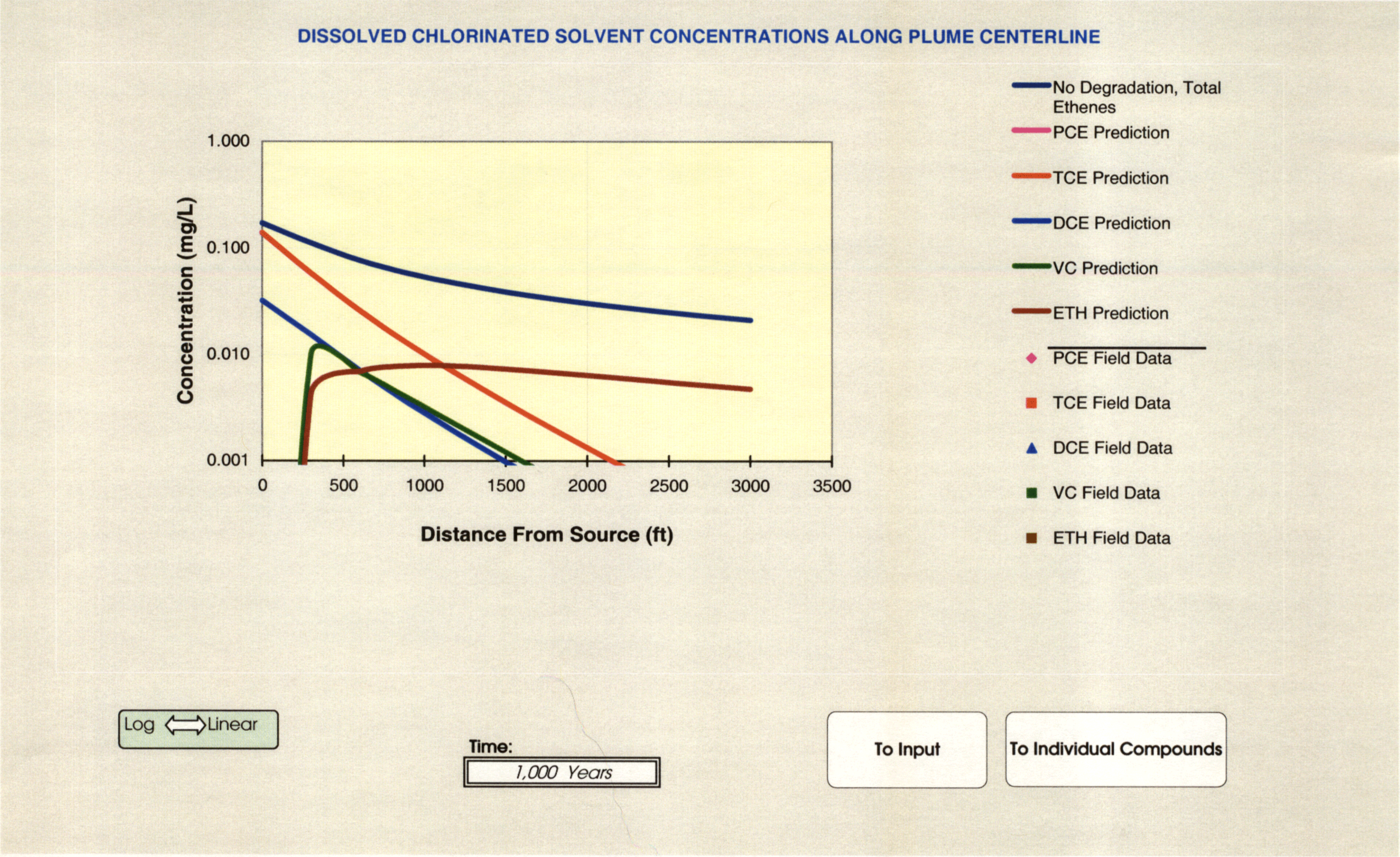
Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)											
Date Data Collected											

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | **RUN ARRAY** | *Help* | Restore Formulas | RESET | *SEE OUTPUT* | Paste Example


DISSOLVED CHLORINATED SOLVENT CONCENTRATIONS ALONG PLUME CENTERLINE
Concentration (mg/L)
1.000
0.100
0.010
0.001
0
500
1000
1500
2000
2500
3000
3500
Distance From Source (ft)
No Degradation, Total Ethenes
PCE Prediction
TCE Prediction
DCE Prediction
VC Prediction
ETH Prediction
PCE Field Data
TCE Field Data
DCE Field Data
VC Field Data
ETH Field Data
Log
Linear
Time:
1,000 Years
To Input
To Individual Compounds

Scenario 4 – 90% reduction in the source zone from treatment

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Camp Lejeune
Site 86 Scn. 4
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in gray
0.02 cells. Press Enter, then (C)
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	315.4	(ft/yr)
or			
Hydraulic Conductivity	K	1.9E-02	(cm/sec)
Hydraulic Gradient	i	0.004	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.33	(-)
(Alpha z) / (Alpha x)*	5.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R

or

Soil Bulk Density, rho	1.7	(kg/L)		
FractionOrganicCarbon, foc	1.0E-3	(-)		
Partition Coefficient	Koc			
PCE	426	(L/kg)	3.90	(-)
TCE	130	(L/kg)	1.88	(-)
DCE	125	(L/kg)	1.85	(-)
VC	30	(L/kg)	1.20	(-)
ETH	302	(L/kg)	3.05	(-)

Common R (used in model)* = 1.88

4. BIOTRANSFORMATION

-1st Order Decay Coefficient*

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.475		0.74
DCE → VC	1.740		0.64
VC → ETH	1.360		0.45

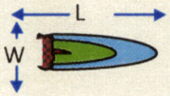
Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	1000	(yr)
Modeled Area Width*	350	(ft)
Modeled Area Length*	3000	(ft)
Zone 1 Length*	3000	(ft)
Zone 2 Length*	0	(ft)



Zone 2= L - Zone 1

6. SOURCE DATA

TYPE: Continuous
Single Planar

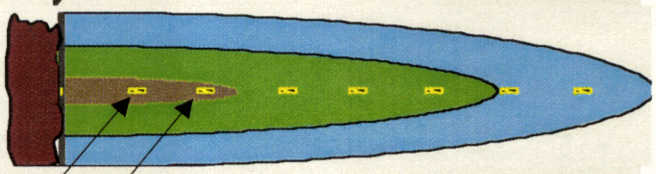
Source Options

Source Thickness in Sat. Zone* 24 (ft)

Y1
Width* (ft) 270

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE	.056	0
DCE	.013	0
VC		0
ETH		0

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)										
TCE Conc. (mg/L)										
DCE Conc. (mg/L)										
VC Conc. (mg/L)										
ETH Conc. (mg/L)										
Distance from Source (ft)										
Date Data Collected										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

RUN ARRAY

Help

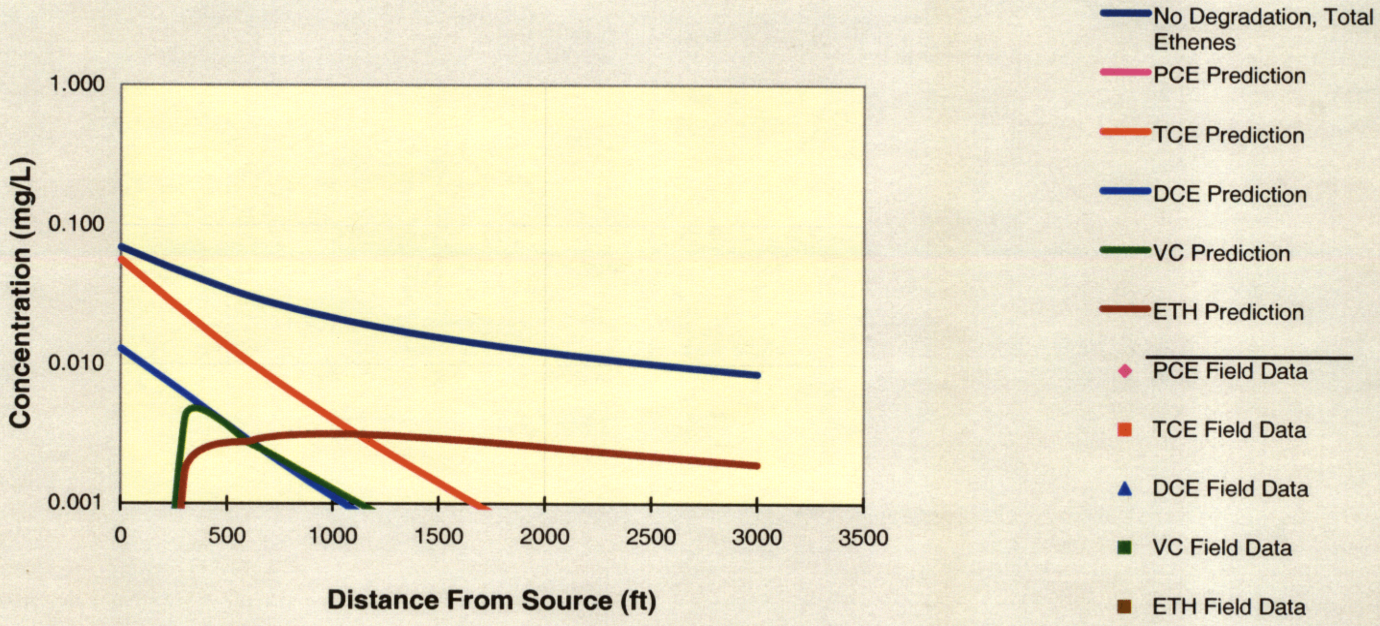
Restore Formulas

RESET

SEE OUTPUT

Paste Example

DISSOLVED CHLORINATED SOLVENT CONCENTRATIONS ALONG PLUME CENTERLINE



Log ⟺ Linear

Time:

1,000 Years

To Input

To Individual Compounds